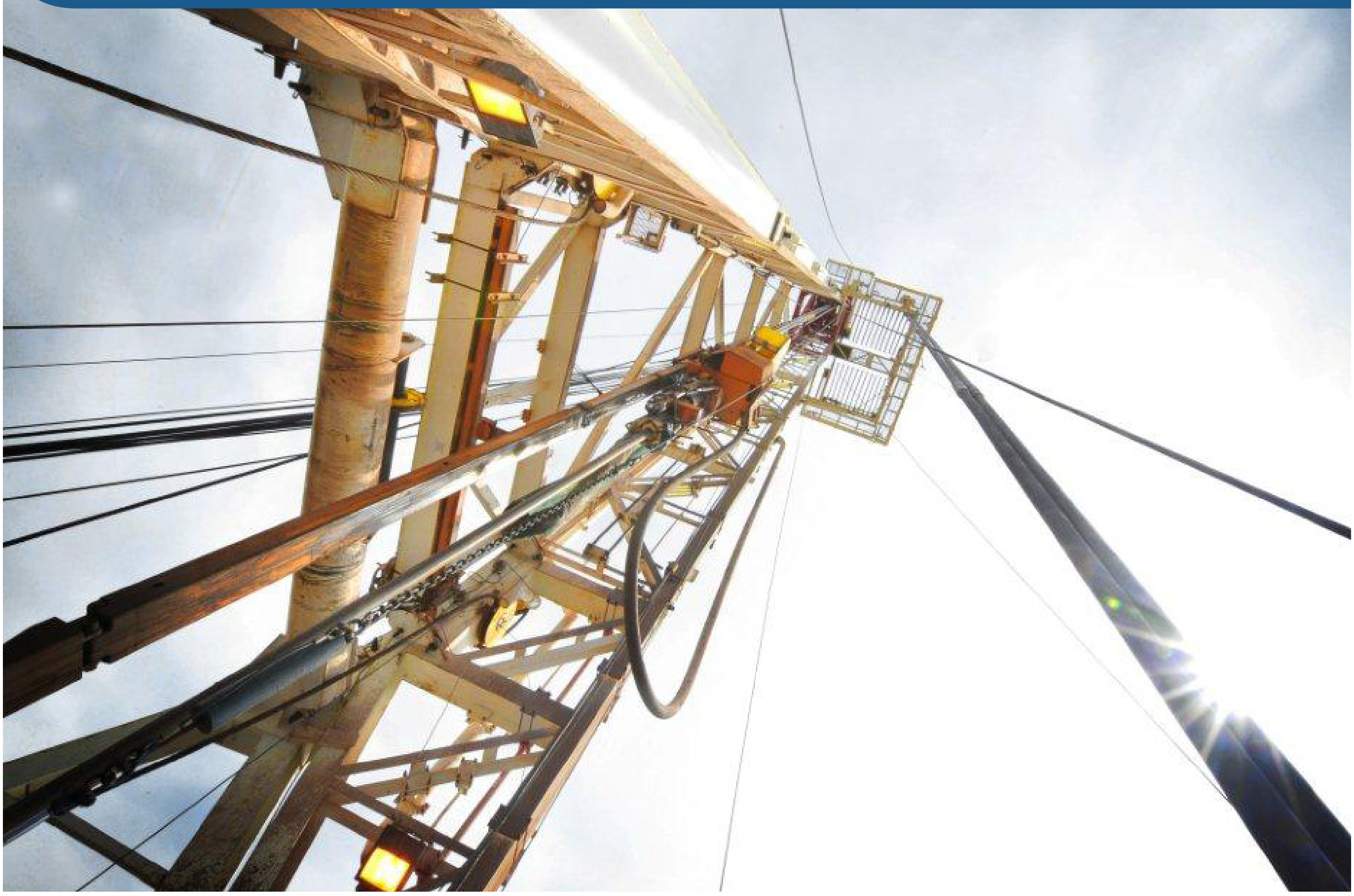
TODD ENERGY

Enterprise & Energy

Hydraulic Fracturing

Submission

to the Parliamentary Commissioner for the Environment



11 October 2012

Dr Jan Wright
Parliamentary Commissioner for the Environment
PO Box 10-241
WELLINGTON 6143

Dear Dr Wright

SUBMISSION TO THE PARLIAMENTARY COMMISSIONER FOR THE ENVIRONMENT'S INVESTIGATION INTO HYDRAULIC FRACTURING IN NEW ZEALAND

1. Introduction

1.1 Todd Energy (Todd) welcomes the opportunity to provide input into your investigation regarding the use of hydraulic fracturing in New Zealand. We hope this investigation will provide the clarity required to properly inform the public on both the merits and perceived risks of hydraulic fracturing in a New Zealand context.

1.2 Todd wants to improve the public discourse on these issues and is strongly committed to assisting in that by providing full transparency about our hydraulic fracturing operations in New Zealand. In that spirit, we have endeavoured to provide a plain language, comprehensive picture of our operations with considerable background detail. We will also make this submission available to the public.

1.3 We reiterate our invitation to you to visit our Taranaki wellsites and observe a hydraulic fracturing operation, and would welcome the opportunity to provide any further information that may be helpful to your investigation.

1.4 There are important differences between types of fracture treatments, target formations, and the depths at which they are performed, and these matters are addressed in considerable detail in the submission as they impact significantly on the level of any possible risks.

1.5 Todd's hydraulic fracturing operations are in line with international best practice, and have developed and will continue to be refined through a process of continuous improvement. They are safe and have minimal impact on the environment. Todd complies fully with the New Zealand regulatory regime, which we regard as sound and fit for purpose. The information and evidence set out in this submission supports this position. The following are the main points of our submission.

2. Regulatory framework for hydraulic fracturing

2.1 The increased public focus on hydraulic fracturing has already prompted the Taranaki Regional Council (TRC) to review and refine regulation of hydraulic fracturing operations in Taranaki.

2.2 The enhanced regulatory framework including specific resource consents, compliance requirements and public disclosure for hydraulic fracturing activities, together with regulations such as the Hazardous Substances and New Organisms Act 1996 (HSNO), adequately protects the environment and is fit for purpose.

2.3 This view is reinforced by the findings of detailed analyses and studies by the TRC and GNS Science in Taranaki which found no detectable evidence of water or air quality contamination or of seismic events arising from or relating to hydraulic fracturing.

2.4 Industry has also responded to public concerns with moves to provide greater transparency around its operations. This should be strongly encouraged.

2.5 Data disclosure requirements under the resource consents should be restricted to relevant data, but should be regularly reviewed to ensure that they remain fit for purpose and allow for innovation.

2.6 The hydraulic fracturing consent framework implemented by the TRC should be adopted by other councils.

2.7 Should further regulation be proposed for hydraulic fracturing, despite the absence of any evidence of significant environmental damage caused by hydraulic fracturing in New Zealand, it should be risk based, and recognise that depth, well construction methods, the types of fluids and chemicals used, and the volumes of water used have a significant impact on the magnitude of the environmental risk.

3. Environmental risks associated with hydraulic fracturing

3.1 Many of the environmental risks raised as concerns relating to hydraulic fracturing apply to all exploration and production drilling. They are well recognised by the industry and managed through adherence to high quality well construction and best practice in all operations.

3.2 The primary environmental concern raised in relation to hydraulic fracturing is the risk of contaminating shallow freshwater aquifers and surface water with hydrocarbons or fracture fluids.

3.3 Todd uses low volume conventional fracturing, typically in sandstones below 3,000 metres, with multiple layers of overburden and cap rock seal. The risk of contaminating a shallow freshwater aquifer or surface water during such treatments is significantly lower than in high volume water fracturing used in shallow shale gas developments in the United States.

3.4 Todd uses state-of-the-art well construction and fracture monitoring procedures. The risk of fractures extending into aquifers or fluids escaping up between the well and surrounding rock is virtually non-existent.

3.5 A potential environmental risk associated with deep hydraulic fracturing in Taranaki would be accidental surface spillage of chemicals or fracture fluids containing low concentrations of mild contaminants. This is effectively managed through strict adherence to high quality health, safety and environmental management procedures and compliance with HSNO and other regulatory controls for the handling, transport and disposal of chemicals and returned fluids.

3.6 The types of chemicals used for hydraulic fracturing have changed substantially over the last twenty years. Most are environmentally benign and are common in many household products. Fracturing fluids that are 100 percent benign are rapidly coming on market. Fracture fluid composition is fully disclosed in consents and on many company websites.

4. Seismicity

4.1 Downhole micro-seismicity (below 2M on the Richter scale) induced by fracturing, is highly unlikely to be felt at the surface. Slightly higher energy events have been linked with fracturing in some countries, typically related to geothermal projects.

4.2 A GNS study conducted in Taranaki concluded it is unlikely that hydraulic fracturing operations have caused detectable earthquakes.

4.3 Public concern has been expressed about the possibility of hydraulic fracturing operations activating a natural fault. The risk of this occurring in deep gas formations in Taranaki is very slight.

4.4 Part of the normal risk assessment involved in planning hydraulic fracturing includes identifying the presence of any faults from seismic reflection surveying data and avoiding these.

4.5 Avoiding hydraulic fracturing near faults is also good operating practice from the perspective of obtaining a successful fracture treatment result. This is because a fault may act as a 'thief zone' for the treatment, thereby compromising the operational objective, and potentially leading to early programme termination.

5. Natural gas as a transition fuel

5.1 Todd supports the move to more sustainable energy sources and has invested in hydro, solar and geothermal assets, and tidal and landfill gas energy developments.

5.2 Nevertheless it is likely that fossil energy sources will continue to play an important role for the foreseeable future. Consumers are not prepared to meet the very large costs that would be necessary to replace the 61 percent of New Zealand's total energy supply met by non-renewable sources, with renewables.

5.3 Solar, wind and hydro energy are very weather dependent and rely on thermal generation as a back-up. The latter two also leave significant environmental footprints.

5.4 As the cleanest burning fossil fuel, with significantly lower greenhouse gas emissions than coal, natural gas is the obvious, affordable, reliable transitional fuel.

5.6 Tight gas resources are required to secure New Zealand's long term gas supply, and their production necessitates the use of hydraulic fracturing.

Paul Moore

Paul Moore
Chief Executive
Todd Energy

This submission has been prepared by Todd Energy to assist the Parliamentary Commissioner for the Environment with her enquiry into hydraulic fracturing. It may not be relied upon by any other person or for any other purpose. While the authors have taken all care to ensure the accuracy of the information in the submission, they accept no responsibility for errors or omissions.

Contents

Table of Figures

Table of Tables

Foreword

As a major New Zealand energy company and one of a number of firms with substantial experience in using hydraulic fracturing in New Zealand, Todd Energy wants to contribute to public understanding of the process of hydraulic fracturing and the related issues surrounding its use.

We have therefore endeavoured in this submission to provide a plain language, comprehensive picture of our hydraulic fracturing operations and their context, and the issues, standards and practices involved.

Chapter 1 provides an overview of Todd Energy's operations, the New Zealand oil and gas sector, background geology and an introduction to hydraulic fracturing techniques.

Chapter 2 is a short history of hydraulic fracturing internationally and in New Zealand, and an overview of public concerns internationally and in New Zealand.

Chapter 3 describes the hydraulic fracturing process in detail.

Chapter 4 describes the regulations governing hydraulic fracturing in New Zealand.

Chapter 5 provides an overview of how Todd Energy uses the technology in New Zealand and its operating standards, policies and practices.

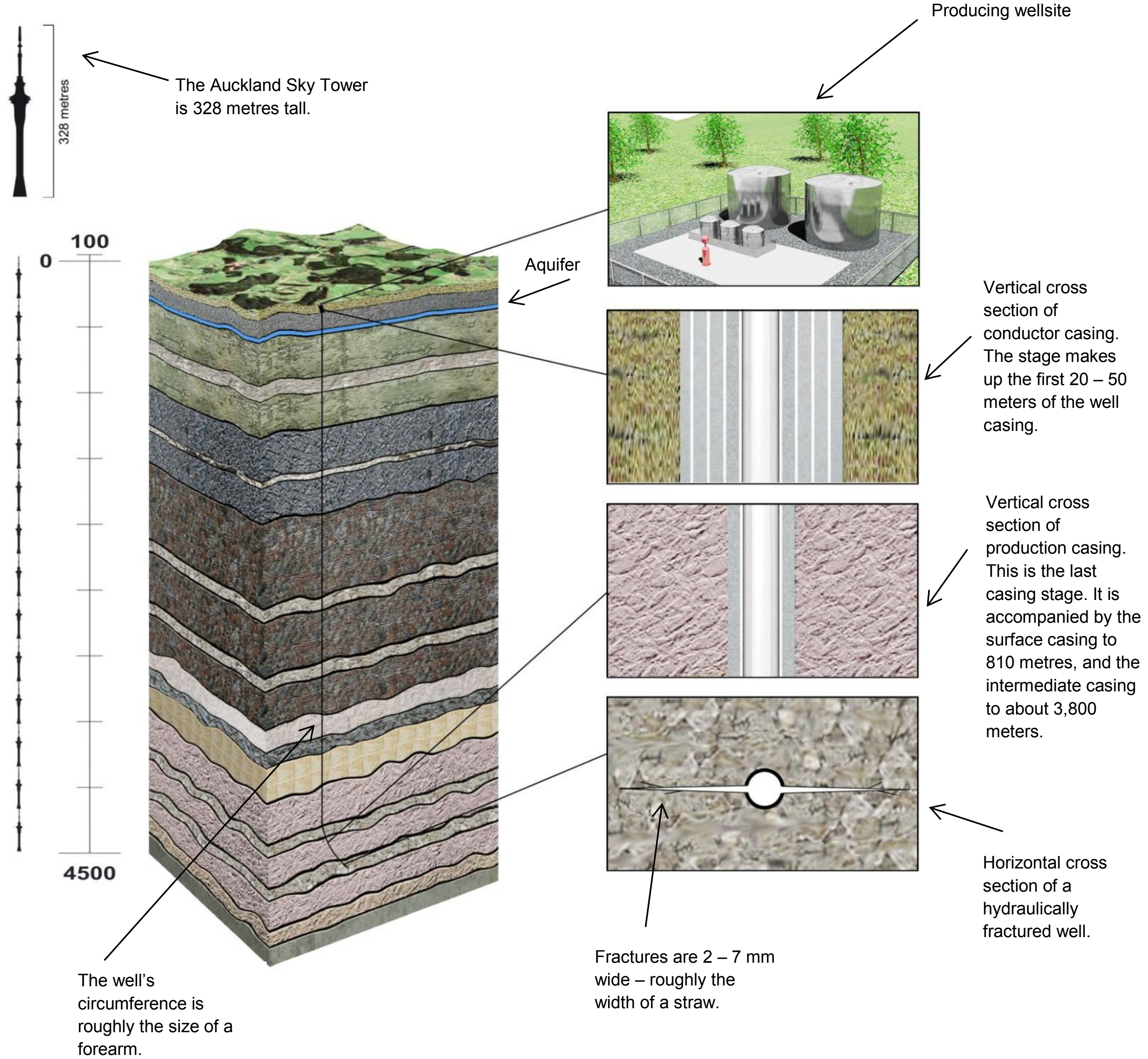
Chapter 6 outlines the potential environmental effects of hydraulic fracturing and how these are mitigated.

Chapter 7 discusses the economic, social and environmental contribution the oil and gas industry makes to New Zealand and the significance of hydraulic fracturing to maintaining and increasing that contribution.

This document has been reviewed by independent experts. Reviewers were not asked to endorse the report's conclusions and recommendations. They acted in a personal and not an organisational capacity. The reviewers and their qualifications are listed in Appendix A.

Cross section of a hydraulically fractured well

Hydraulic fracturing of the type performed by Todd Energy occurs several kilometres underground in carefully selected target formations and well away from freshwater aquifers. The footprint at the surface is very small. Multiple casings of steel and cement ensure that oil and natural gas cannot escape from the well into the surrounding formation and aquifers. The fractures themselves are a few millimetres wide, 30 to 40 metres high and extend a few hundred metres laterally from the well.



Executive Summary

Chapter 1: Introduction

Todd Energy

Todd Energy (Todd) is a 100 percent New Zealand owned and operated company and one of the country's leading energy explorers and producers. It has interests in natural gas, oil, LPG, electricity generation, cogeneration, solar, hydro, geothermal and tidal energy assets. It owns or has interests in six producing fields responsible for over 80 percent of New Zealand's annual hydrocarbon energy production, and holds ten petroleum exploration permits.

Todd operates at international industry best practice and has world-class health, safety and environmental management systems. Its staff and contractors have extensive international expertise and experience in upstream petroleum operations. Over the past 20 years, 15 hydraulic fracturing operations have been undertaken in six Todd-operated wells, with no significant adverse environmental incidents or non-compliance issues.

Todd is a major and growing contributor to the Taranaki and national economies, with plans to invest $760 million in the development of the Mangahewa field over the next few years. Its agreement to supply natural gas to Methanex over the next ten years and the consequent combined capital expenditure by the two firms is estimated to result in an increase in government revenue over this period of $1.2 billion.

New Zealand oil and gas sector

The Taranaki Basin is New Zealand's only commercially producing basin, producing 17 million barrels of oil and 155 PJ of natural gas in 2011. The basin nevertheless remains underexplored by international standards and has considerable potential for further discoveries.

The offshore Maari and Tui fields dominate oil production, while Pohokura and Maui are the largest natural gas producers. Discovery of abundant natural gas in the Kapuni field in 1959 led to government investment in a transmission network throughout the North Island and reticulation in all North Island urban centres. The 1969 discovery of the giant Maui field, combined with the 1970s oil crisis, led the government to invest in a number of "think big" projects including ammonia-urea, synthetic petrol and methanol plants.

In New Zealand, with its "gas bountiful" geology, natural gas has long been a fuel of choice and a critical part of New Zealanders' everyday lives. It is a clean, affordable, efficient, abundant and secure source of energy. As a fuel for generating electricity, natural gas produces approximately 50 percent less carbon dioxide emissions than coal. It is thus both a flexible, reliable back-up for weather-dependent renewable generation, and an ideal transition fuel as we move over time to a future with affordable renewable energy.

Basic petroleum geology

Petroleum (oil and natural gas) forms from organic plant and animal matter in sedimentary rocks, primarily organic rich shales and carbonate rocks known as source rocks. The organic matter is transformed into petroleum by a complex maturation process as a result of the high pressures and temperatures encountered during burial over millions of years.

After the petroleum has formed in the source rock, some of it migrates into reservoir rocks where it exists within the pore space of the rock, much as water would soak into a bucket of beach sand. These petroleum bearing rocks, from which most of the world's hydrocarbons are produced, are known as conventional reservoirs.

Conventional and unconventional petroleum resources

Hydraulic fracturing is used to enhance production in both conventional and unconventional resources. Unconventional resources generally refer to rocks which are either the source of the hydrocarbons stored within or are inter-bedded with organically rich source rocks. Coal seam gas and shale gas are defined as unconventional resources, as the coal and shale are both the source and reservoir rocks. Unconventional resources typically require stimulation to initiate and sustain commercial flow rates, while conventional reservoirs may or may not need stimulation.

Reservoirs suitable for hydraulic fracturing include:

> *tight gas*: generally a term used to characterise low quality conventional reservoir rock, which is charged with gas

> *shale gas*: natural gas trapped within shale formations. Shales are rich in organic matter but have extremely low permeability, and

> *coal seam gas* (CSG, also called coal bed methane): natural gas contained within coal seams. Water and low porosity/permeability in the coal impedes the capacity of the gas to flow freely from the formation.

Hydraulic fracturing techniques

Hydraulic fracturing achieves results similar to those produced by natural fractures caused by the earth's movements over millions of years and commonly found in petroleum-bearing rock. In these fractured formations, fluids seep from the rock and pool naturally in the crevices. The benefits of these fractures in terms of improved flows of oil and gas have long been understood.

The type of hydraulic fracturing technique used depends on the geology of the target formation. The main types of hydraulic fracturing are:

> *Conventional fracturing* (used in New Zealand): long, very thin fractures typically used in tight reservoirs, generally sandstone and 3,000 metres below ground level. The volume of fluid used is usually less than 1,000 cubic metres per fracture treatment. The process utilises four to five pumps operating at a combined rate of up to 32 barrels per minute. Fracture fluids are water-based gels with a medium proppant loading.

> *High-volume water fracturing* (used in the United States): very long, very thin fractures, typically used in very low quality reservoirs (shale and coal) at various depths, usually below 800 metres. It requires the use of high volumes of water. The process utilises 20 or more pumps, operating at a combined rate of up to 150 barrels per minute. Fracture fluids are water-based with a low proppant loading. This technique is often used in conjunction with horizontal drilling for shale gas extraction.

> *Skin fracturing*: short wide fractures. Typically used in high quality reservoirs. Gel-based fracture fluids with a high proppant loading. This is used for small scale fracture operations and to bypass near wellbore damage.

> *Acid fracturing*: used in limestones to create conductive fractures by etching channels in the fracture surface. The fluid is an acid and no proppant is required as the acid dissolves the limestone.

Chapter 2: History and Issues

History of hydraulic fracturing

Hydraulic fracturing has been used commercially worldwide for over 60 years to access natural gas and oil reservoirs that would otherwise be uneconomic or technically impossible to recover.

A primitive and somewhat hazardous form of fracturing using nitroglycerin was first used in the United States over 120 years ago to break up hard rock formations to increase oil flow rates. The benefits were immediately apparent, but it was not until 1949, after many years of experimentation with a range of fluids, that a form of hydraulic fracturing was first used on a commercial basis.

Over the following decades many thousands of treatments were performed using various fluids, including gelled gasoline, crude oil, kerosene and water, together with a 'proppant' – originally screened river sand – to hold the fractures open.

Computer modelling, first applied in the mid-1960s to predict fracture geometry and estimate flow rate improvements, is now highly sophisticated. Developments in well design including horizontal drilling, first used in the 1990s, further improved the process and led to a dramatic expansion of shale gas developments in the United States. It is estimated that hydraulic fracturing will account for 70 percent of US natural gas production in the future and it has also been credited with reducing US carbon dioxide emissions.

Today, after decades of research and refinement and more than a million treatments performed in the United States alone, hydraulic fracturing is a mature, highly developed technology. It is sophisticated, highly engineered and rigorously monitored. It is subject to many precautions both by regulation and industry standards and while, like any industrial process, it poses risks if mismanaged, with the application of international industry best practice, the technology reduces environmental and operational risks to an acceptably low level.

In New Zealand, as in the United States and elsewhere, security of natural gas supply remains an important concern. In this regard, hydraulic fracturing, together with the discovery of vast reserves of natural gas around the world, is having a profound influence on global energy supplies and the world's energy outlook.

Hydraulic fracturing in New Zealand

Like most developed countries, New Zealand has a robust regulatory framework in place to ensure hydraulic fracturing operations meet appropriately high safety and environmental standards. The technology has been used safely and successfully in New Zealand for over 20 years and has become the standard treatment for maximising the efficiency of deep gas wells in Taranaki. Up until mid-2011, a total of 65 treatments had been undertaken in 39 onshore Taranaki wells.

Todd uses hydraulic fracturing mainly in the Mangahewa field near Tikorangi in Taranaki to access natural gas and oil trapped in tight, impermeable rock formations – usually sandstone – at depths of three to four thousand metres. These deeply buried, stacked, low permeability sandstone gas reservoirs are ideally suited to small scale hydraulic fracturing. The formations are separated from freshwater aquifers by at least 2,500 metres of impermeable sealing rock. Todd performs these operations under New Zealand regulation and at international industry best practice and has had no incidents of fresh groundwater contamination.

The benefits to New Zealand of hydraulic fracturing are:

- enhanced well productivity, enabling currently uneconomic wells to be brought into production
- a reduction in the number of wells needed, resulting in a smaller surface 'footprint' and reduced risks and costs
- an increase in accessible natural gas reserves, with increased energy security and reduced dependence on imported hydrocarbons
- a very small 'footprint' on the land. Unlike coal, hydro and wind energy, hydraulic fracturing does not involve large scale landscape disruption. In 2011, Todd's Mangahewa field alone produced as much energy as 89 percent of New Zealand's 456 wind turbines, and

> increased returns to government through royalty and tax payments.

Concerns associated with hydraulic fracturing

Several recent events have prompted public concern about the environmental safety of hydraulic fracturing. These include an increase in the use of hydraulic fracturing in shale gas developments in the United States and shallow CSG developments in Queensland, and seismic events in the United Kingdom and North America that may have been related to hydraulic fracturing. The release of the 2010 movie *Gasland* also received significant public attention.

Much of the concern has been based on misinformation and emotion rather than facts, and the film has since been comprehensively discredited. The oil and gas industry has, however, rightly responded with much greater transparency around its operations and by providing more, readily accessible, detailed information about the technologies it uses.

In the same vein, some governments and regulators have commissioned investigations into the effects of hydraulic fracturing, and a few (including four US states, two Canadian states and France) have imposed moratoria on the use of the technology until their investigations are completed. South Africa and New South Wales recently lifted their moratoria.

The Christchurch City Council and various other district councils and community boards have sought unsuccessfully to impose moratoria on hydraulic fracturing.

The main concerns expressed are:

> possible fresh groundwater contamination

> the possibility of triggering earthquakes

> the migration of natural gas and fracture fluids to the surface, and

> inappropriate handling and disposal of wastes at the surface.

Some critics of hydraulic fracturing also oppose it because they believe it will defer the shift to renewable energy and prolong our reliance on emissions-intensive fossil fuels, and thus increase global warming.

Natural gas is the next best energy source from a climatic perspective after renewables, and is doing much more to reduce global greenhouse gas emissions than all renewable energy sources combined. In the United States the shift from coal to natural gas, made possible by hydraulic fracturing, is estimated to have reduced US carbon dioxide emissions by 400 to 500 megatonnes. This reduction is about twice as large as that attributed to the Kyoto Protocol in the rest of the world.

Observers have noted that, ironically, some of the strongest opposition to hydraulic fracturing and shale gas development comes from traditional oil and gas producers, such as Russian energy giant Gazprom. It has also been noted that the Hollywood anti-hydraulic fracturing blockbuster *Promised Land,* featuring Matt Damon, is being financed by an entity controlled by the government of the United Arab Emirates.

The Taranaki Regional Council (TRC), the only New Zealand territorial authority that currently oversees conventional hydraulic fracturing operations, responded to public concerns by commissioning a series of reports and investigations, specifically relating to effects on seismicity, air quality and groundwater in Taranaki.

GNS Science reviewed the GeoNet earthquake database to establish whether any seismic events had been recorded relating to any hydraulic fracturing or deep well injection activities in Taranaki. They found no such events. The review concluded it was "unlikely" that seismicity induced by hydraulic fracturing would have a significant effect.

The TRC conducted an investigation in March 2012 into water and air quality based on the analysis of 50 parameters, near wellsites where hydraulic fracturing had been used. They concluded there was no evidence of contamination of springwater, groundwater or surface water and there were minimal effects on air quality in the vicinity of flaring.

The TRC released a report on a hydrogeological risk assessment of hydraulic fracturing in Taranaki in May 2012. The report, peer reviewed by GNS Science, concluded there is little risk to freshwater aquifers from properly conducted hydraulic fracturing operations in Taranaki, assuming:

- satisfactory well design, installation and operation and quality control/integrity
- depths well below freshwater aquifers
- the existence of multiple layers of natural, low-permeable geologic seals that trap the hydrocarbons, and
- appropriate industry management and monitoring, compliance with regulation and monitoring by the TRC.

These findings are comparable to research reported in the United Kingdom by the Royal Society and Royal Academy of Engineering *Shale Gas Extraction in the UK: A Review of Hydraulic Fracturing* which found no evidence of contamination and concluded that any health, safety and environmental risks associated with the practice can be effectively managed through the implementation and enforcement of operational best practice.

Potential risks

While these reports and findings give confidence that the New Zealand regulatory regime is fit for purpose and that operations are being conducted at best practice standards, it is important to acknowledge all potential risks, identify how they may arise, and ensure they are effectively managed or mitigated. These are discussed in detail in Chapter 6 and are, in summary:

- poor well construction
- improper hydraulic fracturing operations
- improper disposal of wastes, and
- safety issues relating to high pressure pumping.

These risks are not unique to hydraulic fracturing and are all strictly regulated by resource consents and the monitoring regimes set out in them.

Chapter 3: Process and Science

Operation planning, design and monitoring

Hydraulic fracturing is undertaken by highly specialised international oil field service companies such as Halliburton, Schlumberger and Baker Hughes.

Design of fracture treatments varies greatly between rock types, locations and according to well geometry. Computer modelling is used to optimise operations and design fractures which are constrained within the producing interval and extend laterally far into the reservoir.

Well design and construction

High quality well construction, involving multiple, concentric cemented steel well casings, is central to successful oil and gas operations, including hydraulic fracturing operations.

Good cementing techniques are critical to obtaining the desired hydraulic isolation between zones and between the well and the rock formations. Well designs are specific to each location/field and take account of all well requirements from the initial drilling to the completion and possible stimulation applications, the producing life, and ultimately the time after the well has finished producing.

Stringent standards are in place for the selection of the steel pipe used for the casing strings and for the cement slurry designs used for each hole section. Cement bond logs are used to detect any zones of weakness in the cement.

Wells are specifically designed to withstand high reservoir pressures and the pressures associated with hydraulic fracturing. In addition, extensive pressure testing is undertaken to ensure adequate well casing and cement integrity is achieved, and the pressures in the annuli (the cemented spaces between the strings) is constantly monitored during stimulation operations. Any sudden change in annulus pressure could signal a loss of well integrity, and therefore the pumping operation would be stopped immediately. This effectively eliminates the risk of injecting contaminants into an aquifer zone.

Prior to injecting the fracture fluids, the steel casing of the well is perforated, creating a series of holes linking the well and the target reservoir formation. Fracturing fluids laden with proppant are then injected under high pressure into the reservoir. This process forms fine fractures in the reservoir rock extending away from the well.

Fracture fluids: pumping and composition

Fracturing fluids typically contain 97 to 99 percent water and proppant. Additives are necessary to prevent bacterial build up, clay hydration, and corrosion of the well equipment. The additives also include a gelling agent, such as guar gum, to transport the suspended proppant into the fractures.

Pump trucks supply the pressure needed to pump the fracturing fluid down the well and create the fractures. The fluids from each pump truck are combined at a treatment manifold, from where they are directed down the well. When the pumping stops and the hydraulic pressure is released, the fractures try to close due to the in-situ pressures acting on the formation. The proppant 'props' the fractures open to leave a flow path for the gas or oil.

Fracture formation

The upward and downward vertical growth of the fractures is usually confined by the geology of the surrounding rock layers and stresses on the rock. For a conventional fracture treatment several kilometres underground, a typical fracture will be a few millimetres wide, 30 to 40 metres in height and extend a few hundred metres laterally away from the well.

Various techniques are used to monitor fracture growth, and downhole surveys measure temperature and flow profiles, most commonly involving the application of micro-seismic monitoring and tiltmeters.

Returned fluids

The well is then flowed back to the surface where the spent fracturing fluids are recovered. These are usually stored in lined pits or tanks before being safely disposed of through deep well injection, bioremediation on land farms, flaring or recycling. If the well is capable of flow after hydraulic fracturing, between 25 and 75 percent of the fracture fluids will be immediately recovered. The remainder are either slowly recovered during the production life of the well or may remain in the rock formation. Once the well is in production, the site is remediated and the visual impact is minimal.

Chapter 4: Regulatory Environment

The regulatory framework provides a comprehensive and robust framework for evaluating and managing the potential environmental risks associated with hydraulic fracturing.

Resource Management Act 1991 (RMA)

The RMA establishes the primary control and management of the potential environmental effects of hydraulic fracturing. Regulatory responsibility for granting resource consents authorising hydraulic fracturing operations is split between Regional Councils (e.g. water and air discharges) and District Councils (land use).

Under the RMA a Regional Council has jurisdiction to regulate, and require resource consents for the discharge of chemicals into or onto land, air or water, either on the surface or at any relevant depth below the surface. In practical terms this means that a Regional Council may impose consent conditions related to the casing and sealing of all wells drilled through underground aquifers. This also means that resource consent requirements or conditions can be imposed on the surface or underground discharge of chemicals and water used in hydraulic fracturing operations.

Taranaki Regional Council requirements

As hydraulic fracturing operations have been concentrated in the Taranaki region, the Taranaki Regional Council (TRC) is the regulatory body which has the most experience of regulating hydraulic fracturing operations.

Pursuant to TRC's Regional Freshwater Management Plan (2001) the drilling of a production well (including hydraulic fracturing) is a permitted activity, subject to requirements that all wells must be cased and sealed to prevent potential for aquifer contamination.

As the hydraulic fracturing operations typically regulated under this requirement are at considerable depth (usually in the range of 3,000 metres below ground) the TRC initially determined that the discharge of chemicals at this depth had minimal potential for causing any adverse environmental effects. The depth of any hydraulic fracturing related discharge, the relative depth and impermeability of overlying rock formations between the discharge points and any aquifers, and well casing and sealing requirements were all important factors in the TRC deciding that a resource consent application was not necessary or warranted by any credible potential environmental risks or effects.

A recent regulatory change to require an application for resource consent (for the discharge of chemicals underground, i.e. hydraulic fracturing) enables the TRC to set additional safeguards, in the form of further risk control or safety conditions, to ensure any adverse environmental impacts are avoided. In practice, consent applications for this type of activity are generally not publicly notified under the RMA primarily due to the lack of adverse environmental effects or affected persons. However, limited notification of applications may be required in respect of a limited range of parties considered to have a specific interest or concern.

In the circumstance where the TRC did assess that there were potentially adverse environmental effects arising from a consent application, then full public notification would be required – together with rights of public submission and appeal to the Environment Court. For example, if hydraulic fracturing was proposed at a shallow depth in very close proximity to freshwater aquifers; or where hydraulic fracturing was to be undertaken in different geological conditions where the potential risks of contamination of aquifers were much higher, full notification would be legally required.

To test for any unpredicted environmental impacts and to ensure compliance with consent conditions and requirements, extensive independent monitoring of well sites in Taranaki has been undertaken by the TRC, including water, soil, physiochemical and biological sampling. None of this testing has indicated any adverse environmental effects, including any effects on water quality in freshwater aquifers, caused by drilling or hydraulic fracturing operations.

In the last 10 years, the TRC has conducted over 700 freshwater bio-monitoring surveys, and over 4,600 water or soil samples, with around 30,000 parameter analyses. There have been over 20,000 recorded interactions with the oil and gas industry as part of the TRC's regulation of the industry.

Since mid-2011 the TRC has processed 13 consent applications for hydraulic fracturing activities. These consents have been granted subject to conditions, primarily designed to provide additional levels of assurance that no aquifer contamination or other adverse environmental effect will occur and include expanded monitoring and reporting obligations.

Apart from the regulatory requirements applying directly to drilling activity, well operators also require TRC resource consents for associated activities such as the disposal of drilling water and production water (via land disposal or deep well injection). Flaring gas on a wellsite also requires a resource consent.

Land use consents – district councils

Land use consents under the RMA are required for various activities or operations associated with well drilling activities (including hydraulic fracturing), including noise control, storage of hazardous chemicals, traffic management and any other potential impacts on neighbours or neighbouring land uses. Conditions on restoration of land used for wellsites are also included in land use resource consents.

The Crown Minerals Act (CMA)

The CMA allocates the rights to explore and develop New Zealand's petroleum resources. The Minerals Programme for Petroleum 2005 sets out the allocation method and royalties. The Crown Minerals (Petroleum) Regulations 2007 and the Crown Minerals (Petroleum Fees) Regulations 2006 set out the reporting requirements (including fracturing activities), and fees for operators.

The allocation process for petroleum exploration permits is now through block offer bidding. In allocating the blocks and awarding the permits, the government takes into account the capability, capacity and competency of the bidders.

Taking these elements into consideration at the allocation stage ensures that all companies operating in New Zealand have sufficient expertise and the resources to explore and develop the petroleum resource in accordance with good industry practice, and can comply with all of New Zealand's regulations.

Hazardous Substances and New Organisms Act 1996 (HSNO)

This legislation regulates the handling, storage, use and spill contingency planning applicable to hydraulic fracturing chemicals/fluids and wellsite operations. These requirements include, but are not limited to the preparation of a hazardous chemicals register for the site, readily accessible Material Safety Data Sheets for all hazardous chemicals, HSNO compliance certification, and detailed Spill Contingency Plans.

The Environmental Protection Agency has overall responsibility for ensuring compliance with these requests.

Health and Safety in Employment Act 1992

This legislation, together with associated regulation, Health and Safety in Employment (Petroleum Exploration and Extraction) Regulations 1999, provides detailed requirements for the design, construction and operation (including maintenance) of all petroleum drilling operations (including hydraulic fracturing).

The requirements are administered by the High Hazards Unit of the Ministry of Business Innovation and Employment (MBIE), which is responsible for health and safety in the petroleum industry.

While the primary focus of the High Hazards Unit is the health and safety of employees, the independent assessment of well design, construction and operation also provides safeguards with respect to control of potential environmental impacts or effects due to accidents (e.g. caused by bad well design, malfunction or operational shortfalls) and serves as a second line of independent scrutiny which supplements the assessment of well integrity by the TRC.

Chapter 5: Todd Operations

Overview of Mangahewa operations

Todd has been actively developing productive gas formations using hydraulic fracturing within the Mangahewa field since 2006.

Hydraulic fracturing was first used on the Mangahewa-02 well in May 1997 by the previous operator Fletcher Challenge. This resulted in a significant improvement in well productivity and a commercial flow of gas. The gas bearing formations at Mangahewa are located approximately 3,400 to 4,400 metres below ground level and are far below the known freshwater aquifers which stretch to approximately 400 metres below ground level.

Todd is also a partner in the Kapuni field where Shell Todd Oil Services Ltd (STOS) has undertaken 14 hydraulic fracturing treatments between 1993 and 2011, also at depths well below 3,000 metres.

Unlike the large scale hydraulic fracturing processes used in shale gas extraction, Todd's operations are relatively small scale, and use much less water and equipment over a shorter period of time. The fissures created are between two and seven millimetres wide and approximately 500 metres long along a vertical plane of 20 to 40 metres.

Planning and design

Planning includes a comprehensive assessment of safety, environmental and commercial factors alongside the technical preparations required to undertake the activity successfully. In many cases, it is possible to compare well productivity before and after hydraulic fracturing. Data from the Diagnostic Fluid Injection Test (DFIT) give a reasonable indication of permeability by observing and analysing the rate at which pressure dissipates when the pumping ceases.

Todd's health, safety and environment management system

Todd has maintained an excellent safety and environmental track record in its hydraulic fracturing operations. It has achieved this through applying international industry best practice, meeting all New Zealand safety and environmental regulations, commitment to world-class health, safety and environmental (HSE) management systems, and employing the highest quality staff and industry contractors. Todd invests heavily in the training, development and safety of its people.

Todd uses the services of a leading industry expert, Barree & Associates, located in Denver, Colorado, to design and optimise fracture treatments ensuring minimal risk and maximum flow conductivity. Their 3D simulation software is the most powerful and comprehensive tool available in the industry.

Todd also contracts Baker Hughes, a specialist oilfield services provider, which has its head office in Houston, Texas, to perform the hydraulic fracturing treatments at Mangahewa. Baker Hughes' operational personnel have advanced competency-based training, extensive international experience, and comply with international industry best practice and all local regulatory requirements.

Incident and risk management

Todd's incident management system fosters an open and positive incident reporting culture with its service providers, and is geared towards learning and continuous improvement. Todd also applies a systematic approach to the identification, assessment and control of risk, which commences with hazard identification and analysis at the design phase. Engineering controls are used extensively on pumping and surface equipment to maintain integrity of pressure-containing equipment, and a range of operational risk management tools are employed continuously to control hazards.

Community engagement

In line with its operating principles, Todd recognises that it relies on the goodwill and support of local people for its social licence to operate. It works to understand and acknowledge the needs and sensitivities of local communities and affected groups. It consults regularly with its neighbours, hapū and iwi, local government and community groups on its development programme and operations. Having operated in Taranaki for over 50 years, Todd prides itself on the strong relationships it has built and the positive contribution it makes to the communities in which it operates.

Chapter 6: Potential Environmental Effects and Mitigation

Protection of freshwater aquifers

A key requirement for any onshore oil or gas development is the protection of shallow groundwater resources from possible contamination by chemicals used in the drilling and completion of exploration and production wells.

There have been no documented cases of contamination of freshwater aquifers due to drilling or hydraulic fracturing operations in Taranaki. Nevertheless, there has been public concern about this possibility. However, as noted in Chapter 2 and Chapter 4, detailed assessments by the TRC and GNS Science have concluded there is little risk to freshwater aquifers from properly conducted hydraulic fracturing operations in Taranaki, and the regulatory environment ensures ongoing compliance by the petroleum industry.

In planning hydraulic fracturing operations, four possible means by which shallow groundwater aquifers could potentially be contaminated with fracturing fluids, need to be considered. These are; well integrity failure, a fracture extending into a freshwater aquifer, behind-pipe flow, and surface spillage. These are discussed below.

Well integrity failure

The primary means of protecting groundwater is through proper well construction. In the Mangahewa field, wells are drilled in several stages, with each stage cased by a steel pipe which is cemented into place. By the time the well has reached its final depth a series of at least three concentric 'strings' of cemented steel casings separate the shallow groundwater aquifers from the well.

As noted in Chapter 3, commitment to stringent standards and controls, use of cement bond logs, and continuous monitoring and pressure testing during operations provides further assurance of their safety and integrity.

Fracture extending into aquifer zone

As evidenced in fracture design simulations, Todd's conventional fracturing operations create long lateral fractures with a height of 20 to 40 metres at the most. The height of the fracture is controlled by many factors including the geology of the reservoir, the amount of fluid pumped and the state of stress in the formation. Given these factors, and with several thousand metres of overlying layers of sealing rock, the probability of fractures extending into the freshwater aquifer is very remote.

Behind pipe flow

The escape of fluids between the cement and rock could only occur if there were multiple failures in the cement bonding. The high-quality construction standards and testing and monitoring procedures effectively eliminate this risk.

Surface spillage

Accidental surface spillage is Todd's main environmental concern in planning hydraulic fracturing operations. This could potentially occur during transport, handling, injection, flowback and disposal of fluids. These issues are summarised below. Management of fracturing fluids is however highly and effectively regulated in Taranaki by a comprehensive framework of independently verifiable consents and compliance requirements, and there is no evidence of any groundwater contamination caused by hydraulic fracturing in New Zealand.

Water management

Water acquisition and management has received considerable public attention, primarily because of the very large volumes of water required for shale gas developments in the United States and elsewhere, including Australia. The volume of water used in hydraulic fracturing operations in Taranaki is, however, relatively small and supplies are plentiful.

Water use by Todd and other operators is strictly controlled by the TRC. Resource consents are required to use local water resources and limits are set on maximum daily withdrawals. The mixing of the water with the chemical additives is generally done at the wellsite. While some of the chemical additives may be pre-mixed, the actual fracturing fluid is mixed as the treatment is pumped down the well.

Safe management of returned fluids

Fluids composition

The additives used by Todd are largely those found in everyday household products including food and are fully disclosed in consents. Chemicals that are classified as hazardous substances are significantly diluted and used in compliance with HSNO and any relevant council consents.

Fluids disclosure

Historically, service companies have been reluctant to fully disclose the specific chemical compositions of many components used in hydraulic fracturing due to commercial confidentiality. This position has changed and there is now a strong move towards total disclosure and the use of non-toxic chemicals, which is supported by the oil and gas industry.

Handling, transport and storage

Chemicals are transported to the wellsite in containers specifically designed to minimise the release of chemicals in the case of an accident. Storage containers at the wellsite are also specifically designed for the physical and chemical properties of each particular chemical. In addition, emergency response plans and secondary containment facilities are used to protect against contamination in the unlikely event of a chemical spill.

Treatment of returned fluids

During flowback, the well stream is diverted through a 'sand catcher' and a three-phase separator. The gas is flared in a lined flare pit and the liquids are recovered and stored in tanks ready for subsequent disposal. There are two authorised waste disposal methods in Taranaki: bioremediation ('land farming') and deep well injection (DWI). Land farming involves spreading used fracturing fluid and drilling wastes onto land consented for this purpose. The process, once completed with spreading of fertiliser and topsoil, converts otherwise subfertile sandy coastal land into pasture that can be used for grazing. DWI, which also requires a resource consent, involves pumping the returned fluids down a well and into a sealed deep rock formation.

Flaring is used for safety reasons or because it is necessary to test the production capacity of a well or to prepare it for production. Testing by the TRC confirms that the environmental effect of flaring in these circumstances is negligible. Use of flaring is however kept to a minimum because it wastes valuable gas, and because light, noise and smoke emissions during flaring are undesirable.

Noise

Noise pollution is mitigated by restricting vehicle movements during quiet hours and installing protective sound walls. With the relatively small scale of fracturing operations in Taranaki, and the number of deliveries of equipment and materials being relatively few, noise from trucks has not been a major issue. Well pads are generally further than 500 metres away from the nearest homes.

Seismic activity

Micro-seismic activity induced by fracturing is minor on a geological scale (below 2M on the Richter scale), and not felt at the surface. Slightly higher energy events have been linked with fracturing in some countries, typically related to geothermal projects.

As noted in Chapter 2, a GNS Science study prompted by international events concluded that it was unlikely that any seismic event above magnitude 2M (micro earthquakes) has been triggered by hydraulic fracturing in Taranaki.

Two types of seismicity can be associated with the injection of high pressure fluids into rock formations. The first, known as tensile failure, involves opening new or pre-existing fractures. The second, referred to as shear failure, involves the parallel sliding of the walls of a fracture. Either kind of failure can cause a micro-seismic response detectable at the surface. In hydraulic fracturing the aim is to create a controlled tensile fracture propagating out from the borehole.

Part of the normal risk assessment associated with planning hydraulic fracturing operations includes identifying the presence of nearby faults from seismic reflection surveying data. The risks of generating seismic activity beyond the fracturing operations planned, including the risk of re-activating old faults, are considered to be negligible.

Avoiding hydraulic fracturing near faults is also good operating practice from the perspective of obtaining a successful fracture treatment result. This is because a fault could act as a 'thief' zone for the fracture treatment, thereby compromising the operational objective, and potentially leading to early programme termination.

Emerging technology

Hydraulic fracturing is the subject of intense research and development targeted at further improving the technology. Forthcoming innovations are likely to reduce the need for flaring, involve methods that require less water, and introduce "greener" fracturing fluids. As an example, Chesapeake Energy Corp, the second largest natural gas producer in the United States, is currently testing and developing hydraulic fracturing fluids made entirely of environmentally-benign components.

Chapter 7: Economic, Social and Environmental Benefits

The petroleum sector is a valuable contributor to the New Zealand economy and the New Zealand way of life. As production from the large Maui and Kapuni fields winds down, hydraulic fracturing has become an increasingly important tool for the sector in ensuring long-term security of natural gas supply and maintaining the benefits it provides to New Zealand. Hydraulic fracturing has already enabled or enhanced operations at ten fields in Taranaki: Turangi, Mangahewa, Kowhai, Kaimiro, Ngatoro, Cheal, Kapuni, Rimu, Kauri and Manutahi.

The oil and gas sector contributes $2.2 billion to national GDP annually and provides 6,000 jobs. Labour productivity per worker for direct industry jobs in Taranaki is $525,000, more than five times the national average. In Taranaki, where most exploration and production activities take place, the sector is responsible for 32 percent of the regional GDP. New Plymouth is New Zealand's fastest growing city.

The government expects to receive $2.1 billion in royalty payments from the oil and gas industry for the five years from 2008/09 to 2012/13, including $375 million in the current year. Company and other taxes add to these figures significantly. For example, it is estimated that the government received a total of $1 billion from the oil and gas sector in the 2009/10 year.

Natural gas provided over 19 percent of New Zealand's primary energy supply and 18 percent of the electricity supply in 2011. It is the second most important source of electricity generation after hydro, and a source of backup capacity for times when hydro lake levels are low.

Approximately 247,000 New Zealand households and 10,000 businesses use natural gas (in addition to electricity) to help meet their energy needs. Natural gas is also the feedstock for fertiliser and methanol production in Taranaki by Ballance Agri-Nutrients and Methanex. Methanex's operations are largely dependent on long-term natural gas supply contracts, which hydraulic fracturing helps provide.

The oil and gas sector also provides many intangible benefits to New Zealand. It provides training opportunities, and expertise gained by firms involved in the wider petroleum sector has been applied to areas ranging from geothermal energy generation to super yacht building.

The Mangahewa field development provides an example of the economic contribution that hydraulic fracturing can make to New Zealand. Developing the field will add $400 million to national GDP and provide 1,360 jobs over seven years. Operating expenditure is estimated to add an additional $14 million to GDP per year for 23 years. Royalty payments from the field will be approximately $45 million per year for the first ten years of production.

The Taranaki and wider New Zealand communities benefit from the millions of dollars the petroleum industry spends year each in sponsorship. Todd helps fund many community events and services including the WOMAD (World of Music and Dance) festival, the Todd Energy Aquatic Centre, the Wellington Phoenix Football Club, the Taranaki Kart Club's raceway, Books in Homes, Truant-line, the Life Education Trust and school prize-givings. Todd Energy also recently contributed $227,000 toward the Taranaki Coastguard's new rescue vessel and $3 million toward New Plymouth's Len Lye Centre.

Environmental benefits

Natural gas emits approximately half the emissions per unit of energy of coal. It therefore plays an important role in reducing the carbon dioxide emissions that come from the 61 percent of New Zealand's primary energy supply currently met by fossil fuels. From an environmental perspective, natural gas is the cleanest source of energy after renewables.

Oil and gas firms make a considerable effort to mitigate and offset the effect they have on the environment. The sector makes capital investments in environmental protection and infrastructure enhancements worth millions of dollars each year.

New Plymouth has won several awards in recent years that attest to the quality of life there and underscore that the oil and gas operations in Taranaki are compatible with a high standard of living.

CHAPTER 1

Introduction

This chapter provides background information to petroleum exploration and development in New Zealand, including:

> Todd Energy
> New Zealand oil and gas sector
> Basic petroleum geology
> Petroleum exploration and development
> Conventional and unconventional petroleum resources
> The types of hydraulic fracturing techniques

1.1 Todd Energy

Todd Energy (Todd) is a 100 percent New Zealand owned and operated company and one of the country's leading energy explorers and producers. It was established in 1929 as New Zealand's first indigenous oil company, introducing Europa petrol to motorists in 1933. In 1954, Todd entered oil and gas exploration and production (upstream operations) and, in the 1990s began development of a downstream[1] business. In 2006, Todd established itself as an independent production operator when it took over operatorship of the McKee and Mangahewa fields in Taranaki.

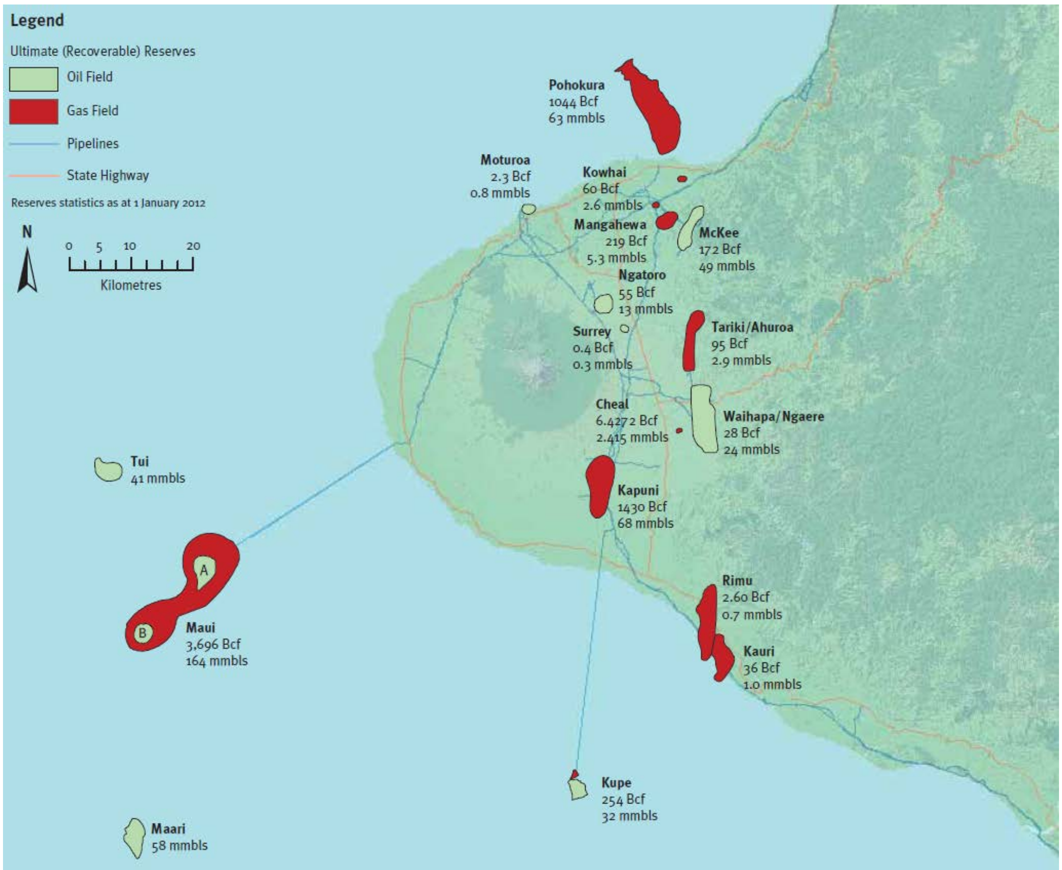
Continuing diversification and extensive investment has enabled Todd to become a vertically integrated energy company, covering the full energy flow from exploration to customer. Today it owns and operates natural gas, oil, LPG[2], electricity, cogeneration and solar water heating assets, and has interests in producing fields responsible for over 80 percent of New Zealand's annual hydrocarbon energy production. Its activities in the Taranaki Basin currently include working interests (WI) in six petroleum mining licences/permits held in unincorporated joint ventures:

- Kapuni gas-condensate field – 50% WI
- Maari oil field – 16% WI
- Maui gas-condensate field – 6.25% WI
- Mangahewa gas-condensate field – 100% WI (Todd operated)
- McKee oil field – 100% WI (Todd operated)
- Pohokura gas-condensate field – 26% WI

[1] This includes electricity generation, and sale of gas, LPG and electricity to factories, businesses and home users.

[2] Liquid petroleum gas.

Figure 1 - Oil and gas fields in the Taranaki Basin[3]



Todd also holds ten petroleum exploration permits (some onshore and some offshore). Its exploration team regularly investigates new business opportunities in the Taranaki Basin, in other New Zealand basins and internationally, either by evaluating farm-ins offered by other companies or by participating in study groups to assess block offers and acreage releases.

The company is a highly competent and capable operator with extensive international experience and expertise in upstream petroleum operations, including hydraulic fracturing. As detailed in this submission, 15 hydraulic fracturing operations have been undertaken in six wells operated by Todd over the past 20 years with no significant adverse health, safety or environmental (HSE) incidents or non-compliance issues. This track record is a result of its commitment to robust, world-class HSE management systems, utilising international industry best practice, and employing the highest quality staff and industry contractors (see Appendix B: Todd Energy Competency Profile and Appendix C: Baker Hughes Service Provider Profile).

Todd is a significant and growing contributor to the Taranaki and national economies and currently employs 438 staff in upstream and downstream operations around the country. Ongoing projects centred on further development of the Mangahewa field will see Todd invest over $760 million in New Zealand over the next few years with several more natural gas wells drilled and a substantial expansion of production facilities in Taranaki. This is expected to add 450 PJ[4] of natural gas into the market over the life of the field.

An agreement signed this year by Todd to supply natural gas to Methanex New Zealand over ten years, has helped enable Methanex to restart its second methanol plant at Motonui. The combined capital expenditure on these projects by Todd and Methanex will

[3] Ministry of Economic Development (NZ), 2012, 'Energy Data File'. http://www.med.govt.nz/sectors-industries/energy/pdf-docs-library/energy-data-and-modelling/publications/energy-data-file/energydatafile-2011.pdf

[4] A petajoule (PJ) is a measure of energy. As a comparison, Wellington used 3.9 PJ of gas and 11.2 PJ of electricity in 2011. See *Ibid.*

create hundreds of jobs regionally and nationally and an estimated increase in government revenue over a ten year period of up to $1.2 billion.

Todd works closely with its neighbours, hapū and iwi, local government and community groups on its development programme and operations. Todd has a deep commitment to safeguarding the environment, and as a socially responsible, family-owned business, it invests heavily in the communities in which it works and in the development and safety of its people.

1.2 New Zealand oil and gas sector

The New Zealand oil and gas sector is a mature industry, primarily concentrated in the Taranaki region. In 2011, oil and gas fields in Taranaki produced 17 million barrels of crude oil and 155 PJ of gas. Oil production is dominated by the offshore Maari and Tui fields while Pohokura and Maui are the largest gas producers.[5]

Oil and gas exploration in New Zealand dates back to 1886 when a well was "dug" next to the Motoroa oil seeps near New Plymouth. Modern exploration commenced in the 1950s utilising new seismic and drilling technologies.

The first major discovery was the Kapuni gas-condensate field in onshore Taranaki in 1959. The size of Kapuni gas reserves, initally assessed at 350 PJ, led the government to invest in the North Island gas transmission network and natural gas reticulation within all connected urban centres. The giant 4,000 PJ Maui field was discovered in 1969. The abundance of gas from these fields, combined with the first oil crisis in the 1970s led the government to invest in a number of "think big" projects to create new markets for the gas and to reduce the country's dependence on oil imports. Those projects included an ammonia-urea plant, the Motunui synthetic petrol plant and the Waitara methanol plant.

Oil and gas exploration in New Zealand dates back to 1886.

The abundance of cheap Maui gas combined with low global oil prices, discouraged further exploration and development drilling activities during the 1980s and 1990s.

Over the last decade rising global oil prices and the decline of Maui reserves has reinvigorated exploration in New Zealand. This has resulted in increased drilling activity since 2003, the development of high value fields such as Tui, and the commercialisation of fields previously deemed uneconomic, such as Kupe.

Despite sub-commercial discoveries of offshore gas in the North Island East Coast area, Canterbury and the Great South Basin, the Taranaki Basin remains New Zealand's only commercially producing basin. Over 400 onshore and offshore exploration and production wells have been drilled to date. The basin nevertheless remains under-explored by international standards and has considerable potential for further discoveries.[6]

Because of its high quality (sweet light crude), almost all of the oil produced in Taranaki is exported. In any event it is not well suited to New Zealand's Marsden Point refinery, which primarily processes a range of imported heavy crudes to meet the country's needs. As a global market for oil always exists, albeit as a price taker, most oil fields are commercially viable. Gas discoveries, however are more marginal, because it is currently not economic to export natural gas, and producers are captive to the small, domestic market.

The oil and gas sector is made up of New Zealand and international exploration and production companies as well as a number of service industries. The sector is a key contributor to the New Zealand and Taranaki economies through providing gas-fired electricity generation, job creation, revenue and exports.

All naturally occurring oil and gas in New Zealand belongs to the Crown. New Zealand Petroleum & Minerals (NZP&M) manages the oil and gas resources, under the Crown

[5] Ministry of Economic Development (NZ), 2012, 'Energy Data File'. http://www.med.govt.nz/sectors-industries/energy/pdf-docs-library/energy-data-and-modelling/publications/energy-data-file/energydatafile-2011.pdf pg. 52.

[6] NZ Petroleum & Minerals (MED), 2012, 'Petroleum Basins'. http://www.nzpam.govt.nz/cms/petroleum/petroleum-basins

Minerals Act 1991. The environmental effects of oil and gas operations are managed through the Resource Management Act 1991. There are additional regulations and acts to manage the drilling of wells and, health and safety as well as oil and gas activities offshore in the Exclusive Economic Zone.

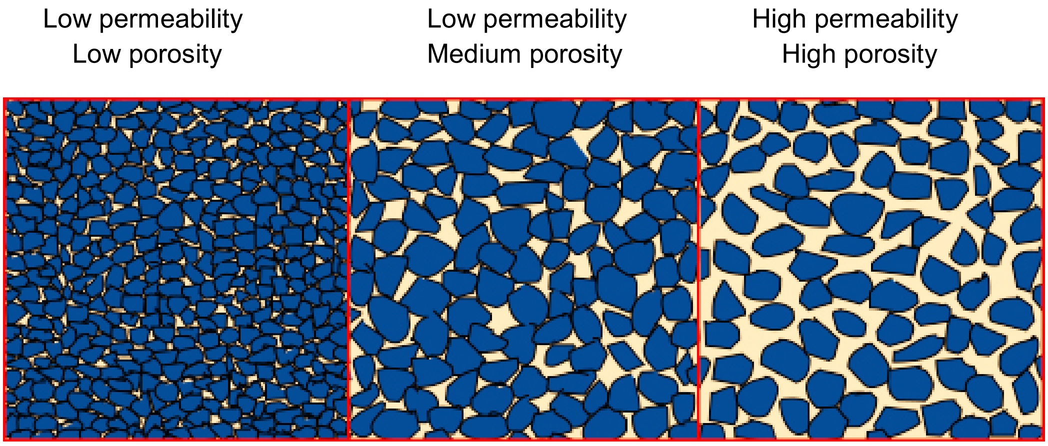
1.3 Basic petroleum geology

Petroleum (oil and natural gas) forms from organic plant and animal matter in sedimentary rocks, primarily organic rich shales and carbonate rocks (for example limestone and dolomite). These rocks are known as source rocks. The organic matter (such as fossil plants) is transformed into petroleum by a complex maturation process as a result of the high pressures and temperatures encountered during burial over tens of millions of years.

After the petroleum has formed in the source rock, some of it migrates out of the source rocks into reservoir rocks. These are typically fine, medium or coarse-grained, porous, and permeable rocks. The petroleum exists within the pore spaces, much as water would soak into a bucket of beach sand. Most of the world's current oil and gas production comes from sandstone and limestone reservoirs.

The amount of pore space between the grains in a rock that could contain fluid is termed porosity. The ability of the rock to permit fluid flow is known as permeability and is measured in milliDarcys (mD). The smaller the milliDarcy, the more impermeable or "tight" the rock is. Being porous and permeable means that the rock contains interconnected passageways of microscopic pores or holes that occupy the areas between the mineral grains of the rock. Figure 2 shows the difference between different levels of permeability and porosity. In the stylised diagrams, oil and gas could exist in the yellow pore space.

Figure 2 - Permeability schematic (not to scale)



Once the oil and gas enters the reservoir rock, it is relatively free to move. Most reservoir rocks are initially saturated with saline groundwater. Because oil and gas are less dense, they rise upward through the saline water-saturated pore spaces until they meet a barrier of impermeable rock known as a seal.

Seals are generally very fine-grained rocks with very little pore spaces or pore spaces that are too small to permit the entry of fluids.

In order for a commercial accumulation of petroleum to form, a trapping mechanism is required to prevent further migration of the oil and gas and to accumulate it in one place. This can be in the form of a dome below seal rock or some other structural feature.

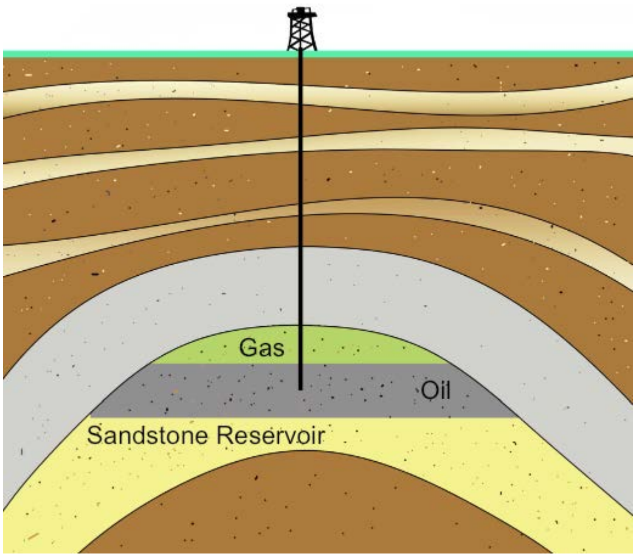
Figure 3, below, shows a simplified petroleum trap. In this diagram, the sandstone is the reservoir rock. The shale (grey area) provides the seal preventing the oil and gas from migrating further. The shale deposits may have also been the source rock for the petroleum.

Because of the depths at which petroleum is located, the fluids contained within rocks are subject to elevated pressure due to one or both of the following factors:

> *Hydrostatic* pressure imposed by the weight of fluid above the reservoir (usually a column of water). A reservoir is considered to be 'normally pressured' if the pressure within the reservoir is equal to the pressure exerted by a full column of water at that depth, and

> *Above hydrostatic* pressure due to the weight of the rocks (and their fluid content) above the reservoir. If the reservoir pressure is greater than the hydrostatic pressure, the formation is referred to as "abnormally pressured" or 'over-pressured'.

Figure 3 - Simplified petroleum system (not to scale)



These pressures are important for the extraction of petroleum. Fluids flow under the influence of an imposed pressure differential between the reservoir and the surface. The rate of flow is dependent on four main factors: permeability of the reservoir, magnitude of the imposed pressure differential, average fluid density, and fluid viscosity. Gas has a much lower fluid viscosity and density than oil or saline water and thus will flow more readily. Production wells may flow naturally if the reservoir pressure is sufficient to push fluids to the surface; otherwise some form of artificial lift may be required, such as downhole pumps.

1.4 Petroleum exploration and development

Finding and developing a petroleum resource can take many years and consists of the following stages:

1. *Exploration*: initial geophysical, seismic and geochemical surveys to locate potential reservoirs, thickness and characteristics of the rocks, for prospective drilling.
2. *Exploration drilling*: drilling of exploration wells to determine the presence/extent of the petroleum-bearing formation(s). This includes the collection of core samples and fluids. Petrophysical data is gathered during logging, where wireline tools are lowered down the well to determine the rock and fluid properties.
3. *Appraisal*: if a discovery has been made, the permit holder has to assess whether it is economic to proceed to development and apply for a mining permit to develop the field. This can require appraisal drilling and well testing, and may involve hydraulic fracturing to determine if a commercial flow from the formation is possible.
4. *Development*: once commerciality has been established the required infrastructure is designed and constructed to allow commercial development of the discovery. This usually includes drilling wells, construction of processing facilities and laying of underground pipelines.
5. *Production*: once the infrastructure is commissioned the wells are put in production. This generally involves 24 hours a day production, and the processing and transporting of the petroleum to market. Additional wells may be

drilled and hydraulic fracturing (or other forms of well stimulation) may be required for the economic recovery of as much of the petroleum as possible.

6. *Decommissioning and restoration*: once the production life ends, the well is plugged and the structures and platforms are removed. The site is restored as per the requirements of the consenting authorities.

It is worth noting that hydraulic fracturing is not in itself an exploration technique. Rather it is used once detailed information about the rock and reservoir properties is known.

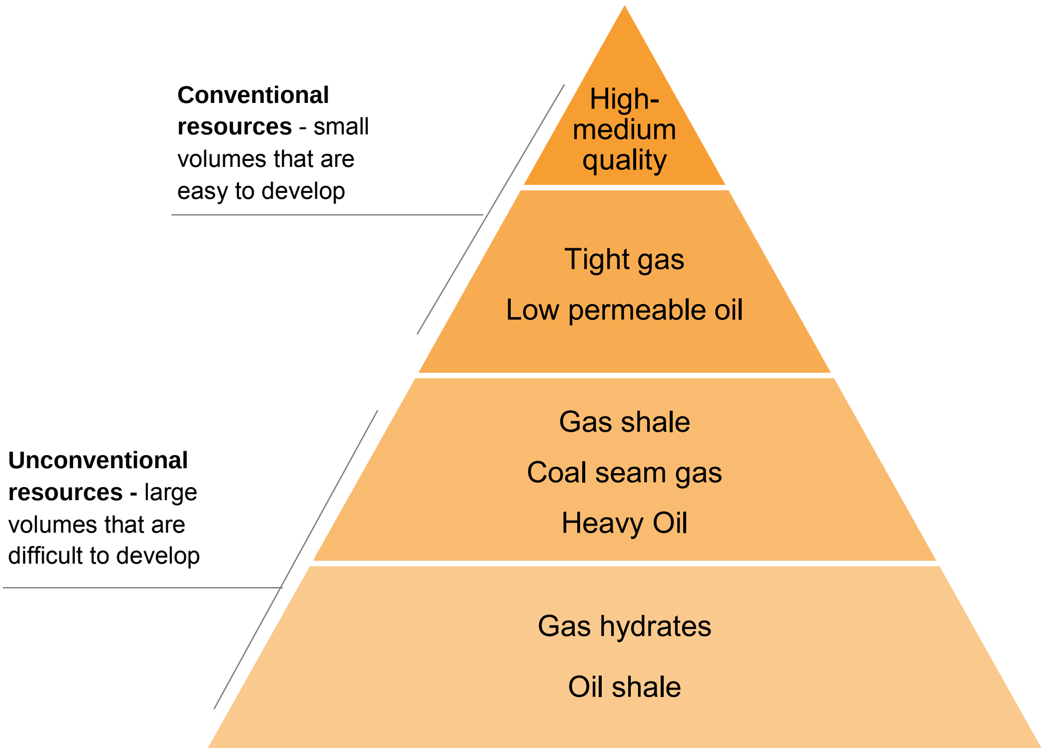
1.5 Conventional and unconventional petroleum resources

Traditionally, oil and natural gas have been extracted from reservoir rocks with relatively high porosity and permeability, so the oil and gas can flow easily from the pore space to the drilled and completed well using natural pressure. Petroleum extracted from these rocks is known as conventional oil or gas.

Unconventional resources generally refers to sources of petroleum that have in the past been too expensive or technically difficult to develop, such as shales which tend to have very fine grains and very small interconnected pores.

Conventional and unconventional resources can be considered on the basis of the resource triangle below (Figure 4). Conventional resources (illustrated at the apex of the triangle) represent a small proportion of the total oil and gas reserves but are less expensive to develop and produce. Unconventional resources depicted by the lower part of the triangle tend to occur in substantially higher volumes but require more costly technologies to develop and produce.

Figure 4 - The resource triangle[7]



[7] International Energy Agency, 2012, 'Golden Rules for a Golden Age of Gas: World Energy Outlook Special Report on Unconventional Gas', *OECD*. www.worldenergyoutlook.org/media/weowebsite/2012/goldenrules/WEO2012_GoldenRulesReport.pdf

It should be noted that tight gas is often a poorly defined category with no clear boundary between tight and conventional, or between tight gas and shale gas.[8] In Europe and New Zealand, tight gas is considered a continuation of conventional gas because the tight sandstones form the reservoir rocks. Coal and shale are defined as unconventional because coal and shale are both the source and reservoir rocks for coal seam gas and shale gas, respectively.[9]

Hydraulic fracturing is used for both conventional and unconventional resources. The main resources that may require hydraulic fracturing are:

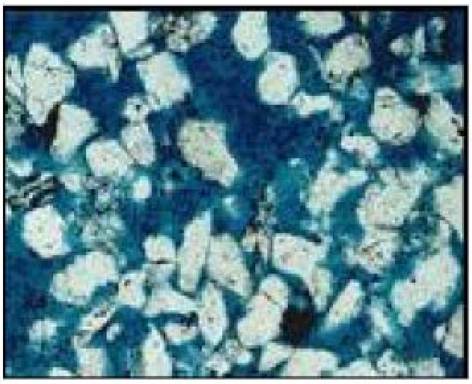
> *Tight gas*: natural gas found in low permeability sandstone/limestone formations that cannot be produced economically without the use of technology to stimulate the flow of the gas towards the well. The majority of hydraulic fracturing treatments in New Zealand have been in tight gas operations.[10]

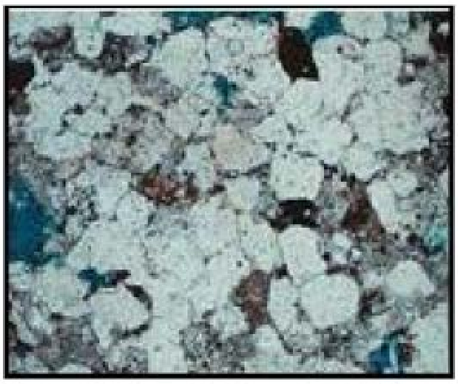
> *Shale gas*: natural gas trapped within shale formations. Shales are commonly rich in organic matter but have extremely low permeability that impedes the capacity of the gas to flow freely from the formation. Because of these properties shales often form the seal rock that traps the petroleum within conventional sandstone and carbonate reservoirs.

> *Coal Seam Gas* (CSG, also known as coal bed methane): natural gas contained within coal seams. Water and low porosity/permeability in the coal formations impede the capacity of the gas to flow freely from the coal formation. In many cases, gas can be produced from the coal without any form of stimulation. However the application of hydraulic fracturing can increase well productivity, allow lower permeability seams to be produced, and reduce the number of wells required.

Figure 5 shows the difference between a typical sandstone reservoir and a tight gas sandstone reservoir. The typical sandstone reservoir (left) has well-connected pores (dark blue). The pores of the tight gas sandstone (right) are irregularly distributed and poorly connected by very narrow pathways.[11]

Figure 5 – A typical sandstone reservoir and a tight gas sandstone reservoir [12]





[8] Pearson, Ivan, et al., 2012, 'Unconventional Gas: Potential Energy Market Impacts in the European Union', *Joint Research Centre Scientific and Policy Reports*, (Joint Research Centre & Institute for Energy and Transport), p. 1. http://ec.europa.eu/dgs/jrc/downloads/jrc_report_2012_09_unconventional_gas.pdf

[9] International Energy Agency, 2012, 'Golden Rules for a Golden Age of Gas: World Energy Outlook Special Report on Unconventional Gas', *OECD*, p. 18. www.worldenergyoutlook.org/media/weowebsite/2012/goldenrules/WEO2012_GoldenRulesReport.pdf

[10] NZ Petroleum & Minerals (MED), 2012, '2012 Block Offer Invitation for Bids', p. 21. http://www.nzpam.govt.nz/cms/pdf-library/petroleum-blocks-offers-1/2012-block-offer/2012%20Block%20Offer%20IFB%20June%207%202012.pdf

[11] AEA, 10 August 2012, 'Support to the identification of potential risks for the environment and human health arising from hydrocarbon operations involving hydraulic fracturing in Europe', *AEA Report to the European Commission* (Issue Number 17). http://ec.europa.eu/environment/integration/energy/pdf/fracking%20study.pdf

[12] *Ibid.*

1.6 Hydraulic fracturing techniques

Hydraulic fracturing achieves results similar to those produced by natural fractures caused by the earth's movements over millions of years and commonly found in petroleum-bearing rock. In these fractured formations, fluids seep from the rock and accumulate naturally in the crevices. The benefits of these fractures in terms of improved flows of oil and gas have long been understood. Natural fracturing is very common, particularly in carbonate reservoirs. If the fractures are open they provide natural, enhanced, flow paths for fluids contained within the pore structure of the matrix[13] rock.[14] If a well is drilled and encounters natural fractures, a large proportion of the flow will come from the fractures that are hydraulically connected to the wellbore, i.e. the fluids in the matrix seep into the fractures and then flow to the well.

Another example of a naturally fractured reservoir is fractured granite where virtually all of the fluids are contained within the fractures as the matrix porosity of the granite is essentially zero.[15] Fractured granite formations are sometimes developed for geothermal application, i.e. production of steam or hot water.

Hydraulic fracturing is used to achieve the enhanced flow benefits present in naturally fractured reservoirs. In many cases, artificial fracture stimulation is required to generate any flow at all. While other forms of reservoir stimulation are available, hydraulic fracturing has become by far the most common technology used.

Chapter 3 describes the process in detail but in summary hydraulic fracturing involves pumping proppant-laden fluid under high pressure into the rock through heavily-encased wells. The process produces fine fissures. The proppant (sand or ceramic beads) remains in the fissures to prop them open and provides a pathway for the gas and oil to flow back up the well. Figure 6 shows an example of proppant used in Todd operations.

Figure 6 - Proppant used in Todd operations

There are several quite different types of hydraulic fracturing. The choice of technique depends on the resource, i.e. tight gas/conventional resources, shale gas or CSG. The main types of hydraulic fracturing are:

> *Conventional fracturing* (used in New Zealand): long, very thin fractures. Typically used in reservoirs with low permeability and tight sandstone reservoirs, generally 3,000 metres below ground level. The volumes of fluid used are typically less than 1,000 cubic metres per fracture treatment.[16] The process utilises four to five pumps operating at a combined rate of up to 32 barrels per minute. Fracture fluids are water-based gels with a medium proppant loading.

> *High-volume water fracturing* (used in the United States): very long, very thin fractures.[17] Typically used in very low quality reservoirs (shales and coal) at various depths typically below 800 metres. For shale gas extraction it is often used in conjunction with horizontal wells and this requires the use of much higher volumes of water, utilising 20 or more pumps operating at up to 150 barrels per minute. Fracture fluids are water-based with a low proppant loading.

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[13] The matrix is also known as groundmass and is the fine-grained material of a rock in which the larger grains may be set.

[14] Aguilera, Roberto, 1995, 'Naturally Fractured Reservoirs', (2nd edition), *Penwell*. www.pennwellbooks.com/natfracres2n.html

[15] Batchelor, Tony, Gutmanis, Jon, Ellis, Fritha, August 2010, 'Hydrocarbon Production from Fractured Basement Formations', *Geoscience Limited*. www.geoscience.co.uk/assets/file/Reservoirs%20in%20Fractured%20Basement%20Ver%209_JCG.pdf

[16] AEA, 10 August 2012, 'Support to the identification of potential risks for the environment and human health arising from hydrocarbon operations involving hydraulic fracturing in Europe', *AEA Report to the European Commission* (Issue Number 17), p. 7. http://ec.europa.eu/environment/integration/energy/pdf/fracking%20study.pdf

[17] *Ibid*, p. 6.

> *Skin fractures*: short wide fractures used to bypass near wellbore damage, typically in high quality reservoirs. This is used for small scale fracture operations and utilises gel-based fracture fluids with a high proppant loading. (Note: this technique was used in the 1990s in the three Kapuni treatments.)

> *Acid fracturing*: used in limestones to create conductive fractures by etching channels in the fracture surface. The fluid is an acid and no proppant is required as the acid dissolves the limestone.

The differences between hydraulic fracturing techniques in New Zealand and those for shale gas and CSG developments in the United States and other jurisdictions are noteworthy in many respects. Throughout this report, the type of hydraulic fracturing referred to and used in New Zealand is "conventional", although skin fracturing was used in the mid-1990s in Kapuni.

Conclusion

Todd is a leading local energy producer. The company operates at international industry best practice, has world-class management systems, and its staff and contractors have extensive international expertise and experience in upstream petroleum operations, including hydraulic fracturing.

The New Zealand oil and gas industry is a strong contributor to the New Zealand and Taranaki economies and plays a critical role in the country's energy security.

In New Zealand conventional hydraulic fracturing treatments are conducted in tight sandstone formations at much greater depth, on a smaller scale and using a very different technique from that used to extract gas from shale and coal formations in the United States. These are important differences, and impact very significantly on the level of any possible risks.

CHAPTER 2

History and Issues

This chapter provides some context for the debate about hydraulic fracturing including:

- The history of hydraulic fracturing
- Hydraulic fracturing in New Zealand
- Concerns associated with hydraulic fracturing

2.1 History of hydraulic fracturing

Fracturing, as a means of reservoir stimulation, dates back to the 1860s when nitroglycerin was used to stimulate shallow, hard rock formations in Pennsylvania, New York, Kentucky and West Virginia. The process was known as "shooting" and was extremely effective in breaking up the rock and increasing oil flow rates and ultimate recovery from the producing wells. The process was, however, extremely hazardous, for obvious reasons.

In the 1930s, the first attempts at using acid to stimulate reservoirs were undertaken. The process, also referred to as "pressure parting", involved pumping at sufficiently high rates and pressures to "break down" the rock formation. The induced fracture would not close completely following pumping because of the acid etching, which created a very fine network of small flow channels on the walls of the induced fracture.[18] Through this work and the development of water injection and squeeze cementing, the physics of the fracturing process became better understood.

Floyd Farris of Stanolind Oil is credited with being the first to conceive of the idea of hydraulically fracturing a well to stimulate production, and this led to the first experimental job, by Stanolind Oil in the Hugoton gas field in Kansas in 1947. This was a very primitive form of the technology using gelled gasoline and sand, followed by a gel breaker.

Figure 7 - Velma, Oklahoma, site of the first commercial hydraulic fracture in 1949[19]

Halliburton performed the first commercial fracturing treatment in Oklahoma on 17 March 1949, with a second job performed on the same day in Texas. The process was a success and in the first year alone, 332 wells were treated.[20]

In 1949, a patent was issued to Stanolind with the treatment referred to as a "Hydrafrac". Stanolind licensed the technology to Halliburton Oil Well Cementing Company in 1949.[21] In 1953 the process was extended to all qualified service companies.[22]

The benefits of fracture stimulation were immediately apparent, with a reported average increase in well productivity of 75 percent. This led to a massive increase in the application through the 1950s, with over 3,000 wells being treated per month.

Up until the early 1950s, treatments were performed with gelled gasoline, crude oil or kerosene. The development of a number of gelling agents, gel breakers, surfactants and clay stabilising agents permitted the use of water as a fracturing fluid from 1953. Most hydraulic fracture treatments today are performed with water-based fluids.

[18] Acid stimulation is still widely used today in limestone formations where the rock is easily dissolved by acids, but is not particularly effective in most sandstone formations.

[19] Halliburton, 2012, 'Hydraulic Fracturing 101', *Hydraulic Fracturing*. http://www.halliburton.com/public/projects/pubsdata/hydraulic_fracturing/fracturing_101.html

[20] Howard, G.C., Fast, C.R., eds (1970), 'Hydraulic Fracturing, Monograph Vol.2 of the Henry L. Doherty Series', *Society of Petroleum Engineers New York.*

[21] Montgomery, Carl T., Smith, Michael B., December 2010, 'Hydraulic Fracturing: History of an Enduring Technology', *JPT: NSI Technologies (2010).* www.spe.org/jpt/print/archives/2010/12/10Hydraulic.pdf

[22] Fisher, Kevin, 2010, 'Data Confirms Safety of Well Fracturing', *The American Oil & Gas Reporter*. http://www.halliburton.com/public/pe/contents/Papers_and_Articles/web/A_through_P/AOGR%20Article-%20Data%20Prove%20Safety%20of%20Frac.pdf

An early discovery in the development of fracturing techniques was the need for a 'propping' agent, known as 'proppant', to keep the fractures from closing completely when the hydraulic pressure is released. The first treatments used screened river sand. Sand remains the main propping agent used today due to its low cost and availability. For specialised applications, such as deep wells, where sand may not have sufficient strength to withstand the forces required to keep the fractures open, other proppants, mainly manufactured ceramic beads, are used.

Early treatments were designed using complex hand calculations, but it was largely a trial and error approach. Computer modelling was applied as early as the mid-1960s and has developed into very sophisticated design programmes employing finely-gridded, finite-element or boundary element models. These programmes can be used to predict fracture geometry in 3D and estimate the improvement in flow potential from the well. These modelling tools are combined with diagnostic post-fracture surveys to refine inputs into the model and calibrate actual results to predicted results.

Natural gas is credited with reducing US carbon dioxide emissions by 400 to 500 megatonnes.

By the end of the 1970s, hydraulic fracturing had become a conventional technique for developing commercial wells in low-permeability tight formations in North America.[23]

Developments in well design have had a major impact on the design of hydraulic fracturing treatments. Up until the 1980s, oil and gas wells were generally drilled vertically (or moderately deviated off the vertical axis) thus only exposing a limited length of the wellbore to the formation. Deviated and horizontal drilling has become increasingly common with the development of new tools and techniques and provides greater exposure of the wellbore to the surface area of the oil or gas bearing formation.

During the 1990s, Texas "wildcatter" George Mitchell, widely regarded as the "father of shale gas fracking", first used horizontal drilling in combination with hydraulic fracturing in the Barnett shale field in Texas. The use of multiple staged fractures along the length of a horizontal wellbore made the commercial extraction of shale gas deposits possible and in turn led to a dramatic expansion of shale gas development in the United States.

It is estimated that hydraulic fracturing will account for 70 percent of domestic natural gas production in North America in the future,[24] and may lead to the rapid development of other major shale gas resources throughout the world. In the United States the shift from coal to natural gas, made possible by hydraulic fracturing, is estimated to have reduced US carbon dioxide emissions by 400-500 megatonnes. This reduction is about twice as large as that attributed to the Kyoto Protocol in the rest of the world.[25]

Hydraulic fracturing has now been used commercially for over 60 years, and in the United States alone, over one million oil and gas wells have been hydraulically fractured.[26] The process is now a standard, conventional methodology in the development and operation of oil and gas fields worldwide. As a direct result of its widespread use in the development of shale gas and CSG resources, the technology is the subject of intense industry development. This is significantly reducing costs, increasing effectiveness and reducing the potential for hydraulic fracturing operations to adversely impact the environment or safety.

Hydraulic fracturing is now a mature and highly developed technology. It is sophisticated, highly engineered and rigorously monitored. It is subject to many precautions both by regulation and industry standards and while, like any industrial process, it poses risks if mismanaged, the application of international industry best practice and the continuous

[23] AEA, 10 August 2012, 'Support to the identification of potential risks for the environment and human health arising from hydrocarbon operations involving hydraulic fracturing in Europe', *AEA Report to the European Commission*, p. 8. http://ec.europa.eu/environment/integration/energy/pdf/fracking%20study.pdf

[24] National Petroleum Council, 15 September 2011, 'Prudent Development: Realizing the Potential of North America's Abundant Natural Gas and Oil Resource'. (Executive Summary can be found at http://www.npc.org/NARD-ExecSummVol.pdf).

[25] See, for example, US Energy Information Agency (EIA) data analysed by Lomborg, Bjorn, in, 13 September 2012, 'A Fracking Good Story', *Project Syndicate*, http://www.project-syndicate.org/commentary/a-fracking-good-story-by-bj-rn-lomborg

[26] Energy Institute, February 2012, 'Fact-Based Regulation for Environmental Protection in Shale Gas Development', *University of Texas at Austin*. http://energy.utexas.edu/images/ei_shale_gas_regulation120215.pdf

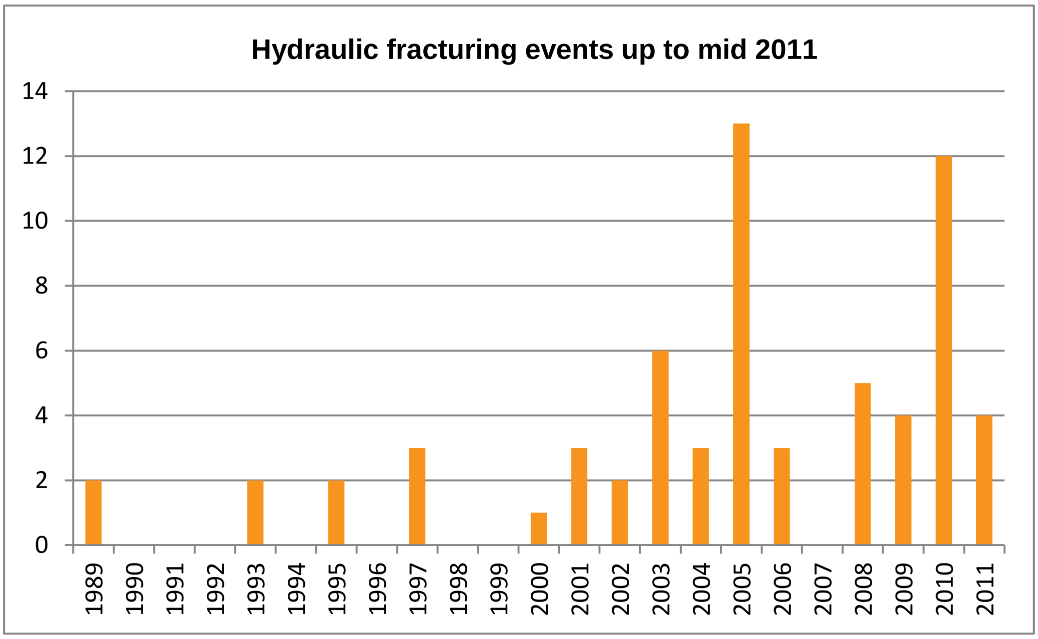
development of new technology reduces environmental and operational risks to an acceptably low level.

In New Zealand, as in the United States and elsewhere, security of natural gas supply remains an important concern. In this regard, hydraulic fracturing, together with the discovery of vast reserves of natural gas around the world, is having a profound influence on global energy supplies and the world's energy outlook.

2.2 Hydraulic fracturing in New Zealand

Like most developed countries, New Zealand has a robust regulatory framework in place to ensure hydraulic fracturing operations meet appropriately high safety and environmental standards. Hydraulic fracturing has been used in New Zealand for over 20 years. One of the first hydraulic fracturing applications in Taranaki was undertaken by Shell Todd Oil Services Ltd (STOS) on the Kapuni-15a well in July 1993.[27] Up until mid-2011, a total of 65 treatments had been undertaken in 39 onshore wells in Taranaki, with most of the activity occurring since 2003, as shown in Figure 8 below. In all cases, hydraulic fracturing has been used to stimulate oil and gas wells targeting tight sandstone reservoirs. To date the technology has not been used in New Zealand for shale gas or multi-stage treatments in horizontal wells.

Figure 8 - Well hydraulic fracture events in Taranaki 1989 to mid-2011[28]



Todd has performed a total of 12 hydraulic fracture stimulations in five wells, mainly within the Mangahewa field. As is clear from the geology of Taranaki's gas fields, these formations are separated from freshwater aquifers by hundreds (often thousands) of metres of impermeable rock. In the case of the Mangahewa field, the reservoir rock is separated from these aquifers by at least 2,500 metres of rocks that are known to have acted as a seal to the flow of hydrocarbons for millions of years.

Hydraulic fracturing has become an essential technology for the development of the low quality, tight reservoirs of the Mangahewa gas field. Without it, a considerable volume of natural gas (and associated condensate) would remain locked in the ground.

[27] Taranaki Regional Council, 17 February 2012 , 'Hydrogeologic Risk Assessment of Hydraulic Fracturing for Gas Recovery in the Taranaki Region'. http://www.trc.govt.nz/assets/Publications/guidelines-procedures-and-publications/Fresh-water-2/fracking-report-feb2012.pdf

[28] Taranaki Regional Council, 28 May 2010, 'Hydrogeologic Risk Assessment of Hydraulic Fracturing for Gas Recovery in the Taranaki Region'. www.trc.govt.nz/assets/Publications/guidelines-procedures-and-publications/hydraulic-fracturing/hf-may2012-main.pdf

Todd performs these operations under New Zealand regulation, meets international industry best practice and has had no incidents of fresh groundwater contamination. Success at Mangahewa has meant the technology can be applied to other marginal accumulations with similar reservoir quality, enabling a greater range of prospects to be considered for commercialisation.

In summary, the main benefits to New Zealand of hydraulic fracturing are as follows:

> Enhanced well productivity, enabling the conversion of sub-commercial, low flow rate gas wells into commercial wells.

> A reduction in the number of wells required to efficiently develop a field, resulting in a smaller surface "footprint", cost savings and a reduced risk of HSE incidents.

> An increase in New Zealand's accessible gas reserves, with reduced dependence on imported hydrocarbon resources.

> A very small "footprint" on the land. Unlike coal, hydro and wind energy, hydraulic fracturing does not involve large scale landscape disruption. In 2011, Todd's Mangahewa field alone produced as much energy as 89 percent of New Zealand's 456 wind turbines combined.

> An increase in exploration and development activity, with a positive impact on employment and the economy as a whole, and the potential for the discovery and development of further reserves.

> An increase in the return to the government from its petroleum resources through increased royalty and tax payments.

2.3 Concerns associated with hydraulic fracturing

Several recent events have prompted public concern about the environmental effects of hydraulic fracturing. These events include an increase in the use of hydraulic fracturing in shale gas developments in the United States and shallow CSG developments in Queensland, and seismic events in the United Kingdom and North America that may have been related to hydraulic fracturing. The release of the 2010 movie *Gasland* also received significant public attention.

However, as noted by Professor Richard Selley in Appendix H2, much of this opposition is based on misinformation and emotion rather than evidence, and the "facts" are often downright wrong. The film *Gasland*, for example, has been comprehensively discredited.[29]

The petroleum industry has, however, rightly responded with much greater transparency around its operations and by providing more readily accessible and detailed information about the technologies it uses. In the same vein, some governments and regulators have commissioned investigations into the effects and operations of hydraulic fracturing in response to these concerns.

In some countries, public concern has resulted in moratoria (or bans) against further application of hydraulic fracturing until detailed assessments have been undertaken. Jurisdictions affected include the United States (New York,[30] Vermont (total ban),[31] New Jersey and Maryland), France (total ban),[32] and Canada (Quebec and Nova Scotia). In September 2012 South Africa and New South Wales lifted their moratoria on shale gas exploration and CSG activities, respectively.[33] Appendix G provides some examples of

Gasland has been comprehensively discredited.

[29] Aardvark, Tory, 23 September 2011, 'Fracking – The Lies Of The Gasland Documentary', *Anthropogenic Global Warming*. http://toryaardvark.com/2011/09/23/fracking-the-lies-of-the-gasland-documentary/

[30] Esch, Mary, 7 September 2012, 'New York Fracking Moratorium Causes Drilling Company To Shut Off Gas In Avon', *Huffington Post* (New York). www.huffingtonpost.com/2012/07/09/avon-ny-new-york-fracking-moratorium_n_1660166.html

[31] Fox News, 17 May 2012, 'Vermont becomes first state to ban fracking', *Politics*. www.foxnews.com/politics/2012/05/17/vermont-becomes-first-state-to-ban-fracking/

[32] Lacey, Stephan, 6 July 2011, 'France Bans Fracking for Shale Gas', *Climate Progress*. http://thinkprogress.org/climate/2011/07/06/261878/france-bans-fracking-for-shale-gas/

[33] Department of Mineral Resources, Republic of South Africa, 2012, 'Investigation of Hydraulic Fracturing in the Karoo Basin of South Africa'. http://www.info.gov.za/view/DownloadFileAction?id=174015

how some international jurisdictions are regulating hydraulic fracturing activities.

Early this year, the New Zealand Government rejected a request from the Christchurch City Council to impose a moratorium on hydraulic fracturing in Canterbury.[34] The Waimakariri District Council and Kaikoura District Council,[35] Spreydon-Heathcote Community Board, Shirley/Papanui Community Board, and the Egmont Plains Community Board have passed resolutions to impose a moratorium on hydraulic fracturing.[36] These resolutions are not enforceable because most activities relating to hydraulic fracturing are regulated by central government or regional councils.

Nevertheless, the main concerns expressed by governments and regulators are:

> possible fresh groundwater contamination

> the possibility of triggering earthquakes

> the migration of natural gas and fracture fluids to the surface, and

> inappropriate handling and disposal of wastes at the surface.[37]

Some critics of hydraulic fracturing also oppose it because they believe it will defer the shift to renewable energy and prolong our reliance on emissions-intensive fossil fuels, and thus increase global warming.

Natural gas is in fact the next best energy source from a climatic perspective after renewables, and is doing much more to reduce global greenhouse gas emissions than all renewable energy sources combined. As noted in section 2.1, it has been credited with reducing US carbon dioxide emissions.[38]

Observers have noted that, ironically, some of the strongest opposition to hydraulic fracturing and shale gas development comes from traditional oil and gas producers, such as Russian energy giant Gazprom. It has also been noted that the Hollywood anti-hydraulic fracturing blockbuster *Promised Land,* featuring Matt Damon, is being financed by an entity controlled by the government of the United Arab Emirates.[39]

The Taranaki Regional Council (TRC), the only New Zealand territorial authority which currently oversees conventional hydraulic fracturing operations, responded to public concerns by commissioning a series of reports and investigations, specifically relating to the effects on seismicity, groundwater and air quality in Taranaki.

At the request of the TRC, GNS Science reviewed the GeoNet earthquake database to establish whether any hydraulic fracturing or deep well injection (DWI) related seismic events have been recorded in Taranaki.[40] No such events were found. The GeoNet system can detect and locate seismic events of about magnitude M2 and higher. A seismic event needs to reach M4 to M5, 1,000 to 30,000 times more powerful than an M2 event, to cause damage. GNS Science concluded that it is "unlikely that any earthquakes

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[34] Anderson, Vicki, 27 February 2012, 'Energy minister rejects moratorium on fracking', *The Press*. http://www.stuff.co.nz/the-press/opinion/perspective/6483146/Energy-minister-rejects-moratorium-on-fracking

[35] Reid, Neil, 19 February 2012 'Fracking the new 'nuke-free'', *Stuff.co.nz*. http://www.stuff.co.nz/national/6443329/Fracking-the-new-nuke-free

[36] Anderson, Vicki, 12 March 2012, 'Community boards urge moratorium on fracking', *The Press.* http://www.stuff.co.nz/the-press/news/6558204/Community-boards-urge-moratorium-on-fracking

[37] See US Department of Energy, 18 August 2011, 'Shale Gas Production Subcommittee 90-Day Report', *Secretary of Energy Advisory Board*. www.shalegas.energy.gov/resources/081811_90_day_report_final.pdf, and, US Department of Energy, 18 November 2011, 'Shale Gas Production Subcommittee Second 90-Day Report', *Secretary of Energy Advisory Board*. http://www.shalegas.energy.gov/resources/111811_final_report.pdf

[38] The Economist, 25 May 2012, 'America's falling carbon-dioxide emissions: Some fracking good news', *Schumpeter business and management.* http://www.economist.com/blogs/schumpeter/2012/05/americas-falling-carbon-dioxide-emissions

[39] Ridley, Matt, 2011,'The Shale Gas Shock', *The Global Warming Policy Foundation*, (Report 2), http://www.thegwpf.org/wp-content/uploads/2012/09/Ridley-ShaleShock.pdf, p. 16.

McAleer, Phelim, 2 October 2012, 'Frack film's flim-flam', *New York Post*. http://www.nypost.com/p/news/opinion/opedcolumnists/frack_film_flim_flam_4gIUgQnwOYsQpki2RRj9YJ

[40] Sherburn, Steven, Quinn, Rosemary, February 2012, 'An Assessment of the Effects of Hydraulic Fracturing on Seismicity in the Taranaki Region', GNS Science, *GNS Science Consultancy Report 2012/50*. http://www.es.govt.nz/media/21206/assessment_of_the_effects_of_hydraulic_fracturing_on_seismicity_in_the_taranaki_region.pdf

that may be induced by hydraulic fracturing operations in the Taranaki Region would have a significant effect."[41]

In March 2012 the TRC investigated water and air quality near wellsites where hydraulic fracturing had been used. The TRC found that there was no evidence of contaminated springwater, groundwater or surface water surrounding the sites. The analysis covered almost 50 parameters and tested for compounds commonly associated with hydraulic fracturing as well as general exploration and well development.[42]

The Council's investigation of air quality concluded that there were minimal effects on air quality in the vicinity of the flare being employed for the destruction of hydraulic fracturing fluids, in the context of prevailing air quality within the region and nationwide.[43]

In May 2012 the TRC released its report into the hydrogeological risk assessment of hydraulic fracturing in Taranaki. The report, which was peer reviewed by GNS Science, concluded that there is little risk to freshwater aquifers from properly conducted hydraulic fracturing operations in Taranaki, assuming a combination of natural geologic factors, the use of good practices by industry, and regulation by the Council as follows:

> Satisfactory methods for well design, installation, and operation are used with quality control checks to ensure well installation integrity.

> Hydraulic fracturing occurs at depths far below freshwater aquifers.

> The existence of natural petroleum hydrocarbon reservoir seals that trap the hydrocarbons in place.

> Substantial thicknesses and multiple layers of relatively low permeability geologic seals between the petroleum hydrocarbon reservoir and any freshwater aquifers.

> Operational management and monitoring by the industry and regulation and monitoring (including sampling and auditing operational data) by the TRC.[44]

These findings are comparable to research reported in the United Kingdom by The Royal Society and Royal Academy of Engineering in their joint report *Shale Gas Extraction in the UK: A Review of Hydraulic Fracturing*.[45] The review found that the health, safety and environmental risks associated with hydraulic fracturing can be effectively managed through the implementation and enforcement of operational best practices.[46] The risks are even lower when fracturing sandstones, which require lower treatment pressures than shales (at a similar treatment depth), and have a lower risk of propagating beyond the target interval. With regard to claims that shale gas extraction has contaminated water wells, the report concluded that "none has shown evidence of chemicals found in hydraulic fracturing fluids".[47]

There is little risk to freshwater aquifers from properly conducted hydraulic fracturing operations in Taranaki.

2.3.1 Potential risks

While the above reports and findings give confidence that the New Zealand regulatory regime is fit for purpose and that operations are being conducted at best practice standards, it is important to acknowledge all potential risks, identify how they may arise,

[41] *Ibid*, p. 5.

[42] Taranaki Regional Council, 13 March 2012, 'Ngaere water is good, final tests confirm', *Region and Council.* http://www.trc.govt.nz/ngaere-water-is-good-final-tests-confirm/

[43] Taranaki Regional Council, May 2012, 'Investigation of air quality arising from flaring of fracturing fluids – emissions and ambient air quality', *TRC Technical Report 2012-03*, p. 44. http://www.trc.govt.nz/assets/Publications/guidelines-procedures-and-publications/hydraulic-fracturing/Flaring2012-report.pdf

[44] Taranaki Regional Council, 17 February 2012 , 'Hydrogeologic Risk Assessment of Hydraulic Fracturing for Gas Recovery in the Taranaki Region', p. 32. http://www.trc.govt.nz/assets/Publications/guidelines-procedures-and-publications/Fresh-water-2/fracking-report-feb2012.pdf

[45] The Royal Society and The Royal Academy of Engineering, June 2012, 'Shale gas extraction in the UK: a review of hydraulic fracturing', *United Kingdom.* http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/projects/shale-gas/2012-06-28-Shale-gas.pdf

[46] *Ibid*, p. 4.

[47] *Ibid*, p.12.

and ensure they are effectively managed or mitigated. These are discussed in detail in Chapter 6 and are, in summary:

> Poor well construction resulting in contamination of potable freshwater aquifers. The importance of high quality well construction is not however limited to hydraulic fracturing; it is critical to all oil and gas drilling and production operations. Todd, which has significant expertise in managing well integrity, would not utilise hydraulic fracturing if the well integrity did not meet the highest required standards.

> Improper hydraulic fracturing operations resulting in contamination of freshwater resources or surface waters. Again, this is not specific to hydraulic fracturing, but applies to any drilling or production operation. Moreover, this risk is considerably lower for sandstone fracturing than for shale fracturing and the risk diminishes rapidly with depth, i.e. there is vertical separation between freshwater aquifers near the surface and the target reservoirs for hydraulic fracturing.

> Improper disposal of wastes generated by hydraulic fracturing (and drilling and production operations in general) resulting in environmental contamination. This is strictly regulated by resource consents and the monitoring regimes set out in them.

> Safety relating to high pressure pumping. This is not unique to hydraulic fracturing and applies to any drilling or production operation. This is regulated by consents and regulations, and is managed through thorough and structured training, and adherence to appropriate HSE management frameworks. These include hazard and risk management, incident reporting and investigation, emergency response, spill contingency plans and requirements for contractor management. For example, the experience in Australia is that all hydraulic fracturing incidents that have warranted formal investigation have been related to operational errors resulting from poor training of operating personnel.

These risks are not unique to hydraulic fracturing and are all strictly regulated by legislative, regulatory requirements and the monitoring regimes set out in them.

Conclusion

Hydraulic fracturing has been used commercially for over 60 years to access natural gas and oil reservoirs that would otherwise be uneconomic or technically impossible to recover.

After decades of research and refinement and more than a million treatments performed in the United States alone, hydraulic fracturing is a sophisticated, highly developed, mature technology. It is highly engineered and rigorously monitored and regulated. With the application of international best practice, the technology reduces environmental and operational risk to an acceptably low level.

Hydraulic fracturing has been used safely and successfully in New Zealand for over 20 years and has become the standard treatment for maximising the efficiency of deep gas wells in Taranaki. Up until 2011, a total of 65 treatments had been undertaken in 39 onshore Taranaki wells.

The recent increase in the use of hydraulic fracturing in shale gas and coal seam gas developments internationally and the release of the 2010 movie *Gasland* provoked public concern about the environmental effects of the process. Much of the concern has been based on misinformation and emotion rather than facts, and the film has since been comprehensively discredited.

Rigorous, independent studies have been commissioned into the effects of hydraulic fracturing in New Zealand and other countries (including a landmark study in the United Kingdom), and these have concluded that the risks associated with hydraulic fracturing are minor if industry best practice and regulations are implemented and enforced.

CHAPTER 3

Process and Science

This chapter details the hydraulic fracturing process including:

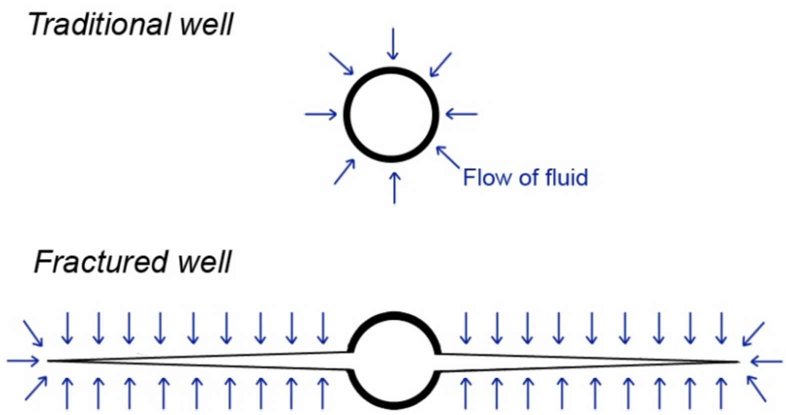
> Operational planning, design and monitoring
> Well design and construction
> Well perforation
> Pumping fracture fluid
> Fracture formation
> Management of returned fluids

3.1 Hydraulic fracturing process

Hydraulic fracturing involves pumping water-based viscous fluid containing proppants at high rates and high pressures into the rock formation. The pressure experienced at the rock face is sufficient to induce fine fractures extending away from the well. As the pumping continues, the fractures are opened by the pressurised fluid that enters them and continue to grow away from the well, extending deeper into the reservoir (also known as the producing formation).[48] The fractures create increased flow channels for production by increasing the effective permeability of the rock. The pressure is then released allowing the fluid to return to the well. The proppant remains in the fractures to prevent them from closing.

A wellbore in a traditional non-fractured well is schematically represented in the top part of Figure 9 below, where the blue arrows represent the flow of fluid to the circle representing the well. By creating an artificial fracture, conductivity paths are created allowing molecules of gas, which were previously isolated, to travel through the formation and fractures to the well and flow on up to production. This situation is represented in the lower part of Figure 9.

Figure 9 - Comparison between a fractured and a non-fractured well[49]



There are six main stages in conducting a hydraulic fracturing operation. These are summarised in Figure 10 below.

3.1.1 Operation planning, design and monitoring

Hydraulic fracturing is a highly specialised and technically advanced process. It is generally undertaken by experienced oil field service companies such as Halliburton, Schlumberger and Baker Hughes, or specialised consultants. Such companies and consultants are also able to provide modelling and design services (see Appendix C for Baker Hughes Contractor Competency Profile).[50]

[48] See Hubbert, M.K., Willis, D.G.W., 1957, 'Mechanics of hydraulic fracturing', *Transaction of the American Institute of Mining, Metallurgical, and Petroleum Engineers Incorporated*, and

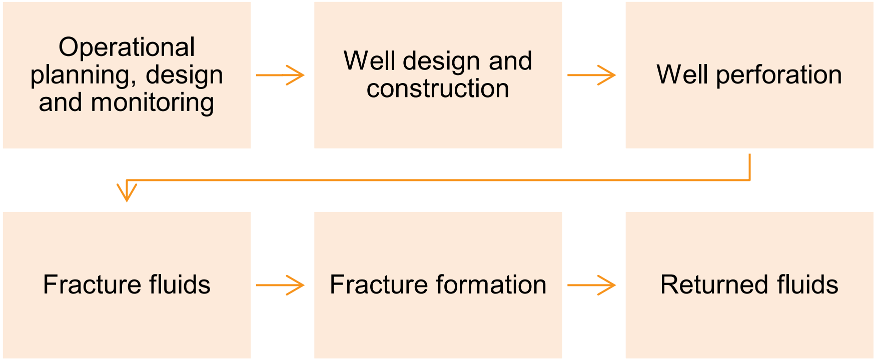
Veatch R.W., Jr., Moschovidis, Z. A. and Fast, C. R., 1989, 'An Overview of Hydraulic Fracturing', in Gidley, JL, Holditch SA, Nierode, DE and Veatch, RW Jr (eds): *Recent Advances in Hydraulic Fracturing*, Monograph 12, USA Society of Petroleum Engineers (1989): pp. 1-38.

[49] American Petroleum Institute, October 2009, 'Hydraulic Fracturing Operations-Well Construction and Integrity Guidelines, First Edition/October 2009', *API Guidance Document HF1*. http://www.api.org/~/media/Files/Policy/Exploration/API_HF1.ashx

[50] Halliburton, 2012, 'Hydraulic Fracture Consulting', *Products & Services*. www.halliburton.com/ps/Default.aspx?navid=2404&pageid=5107, and

Baker Hughes, 2012, 'MFrac Design and Evaluation Simulator', *Reservoir Development Services/ Hydraulic Fracturing*. www.bakerhughes.com/products-and-services/reservoir-development-services/reservoir-software/hydraulic-fracturing/mfrac-design-and-evaluation-simulator

Figure 10 - The hydraulic fracturing process



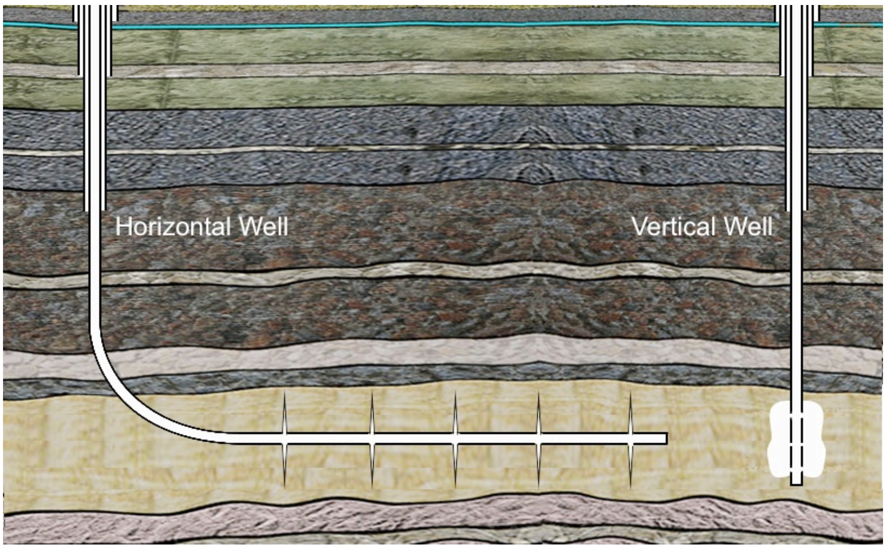
Specific hydraulic fracturing job designs vary significantly between different rock types, geographical locations and even between wells within the same field. A successful design will result in fractures that are constrained within the producing interval and that extend far into the reservoir, with proppant adequately placed throughout the entire fracture.

The type of fracture stimulation depends largely on the geometry of the well. Wells are typically classified as vertical, deviated or horizontal. For the purpose of hydraulic fracturing, a deviated well is essentially the same as a vertical well. The vast majority of onshore wells in Taranaki are deviated.

Horizontal wells are increasingly being used in the United States, particularly in the development of shale gas.[51] Horizontal wells typically have hundreds to thousands of metres of horizontal section within the producing formation. These wells require multiple fracture treatments spaced along the full length of the horizontal wellbore. This is commonly referred to as multi-stage fracturing, with relatively short vertical fractures typically placed every 100 to 200 metres along the horizontal wellbore. This results in considerably enhanced reservoir exposure and commercially viable flow rates.

Figure 11 below illustrates the difference between a multistage fracture treatment of a horizontal well and a fracture stimulation of a vertical well.

Figure 11 - Comparison between a vertical well and a horizontal well[52]



[51] US Department of Energy, April 2009, 'Modern Shale Gas Development in the United States: A Primer', (prepared by the Ground Water Protection Council). http://www.netl.doe.gov/technologies/oil-gas/publications/epreports/shale_gas_primer_2009.pdf

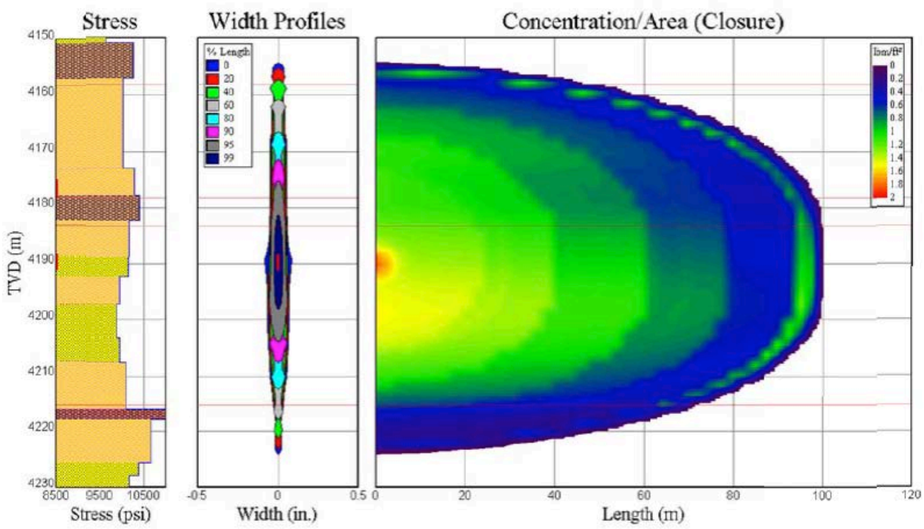
[52] American Petroleum Institute (API), October 2009, 'Hydraulic Fracturing Operations – Well Construction and Integrity Guidelines', *API Guidance Document HF1, First Edition*. www.api.org/policy-and-issues/policy-items/hf/api_hf1_hydraulic_fracturing_operations.aspx

Computer modelling is used to optimise the hydraulic fracturing design. The main input parameters include fluid and rock properties, the sub-surface stress field, well geometry, pressure and temperature, plus equipment specifications. Field data from previous jobs is used to calibrate models and further refine the accuracy of the predictions. Pre-treatment quality control and testing is carried out to ensure a high-quality outcome and to minimise the risks associated with the treatment.

Various techniques are available for monitoring fracture growth before, during and after the pumping operations. Tracers may be added to the fracturing fluid or to the proppant itself.[53] The tracer concentrations are monitored after flowback to assess where various proppant stages have been placed and to compare this to the designed placement.

An example of a computer simulation output is shown in Figure 12. This is a 2D representation of a propped fracture showing the fracture width versus depth (Y-axis) and distance from the well (X-axis). The various colours represent fracture width (dark is narrow, bright is wide). The centre image represents a vertical fracture as it would appear from inside the wellbore. The right hand image is a side view of the fracture. Note the side view only shows one half of the fracture as it propagates to the right. The fracture will also propagate to the left, typically as a mirror image of the right hand side.

Figure 12 – Example of graphical output from hydraulic fracture simulation modelling[54]



Data is gathered during fracture stimulation operations and these can be used to calibrate the computer models to improve the accuracy of future jobs. Downhole surveys measure temperature and flow profiles across the intervals of interest.[55] This can help define the productive intervals or zones, and determine the effectiveness of the fracturing treatment. The most commonly used techniques involve the application of micro-seismic monitoring and tiltmeters.[56] Arrays of both seismometers and tiltmeters may be run into adjacent monitoring wells to detect micro-deformation and micro-seismic events.

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[54] US Department of Energy, April 2009, 'Modern Shale Gas Development in the United States: A Primer', (prepared by the Ground Water Protection Council). http://www.netl.doe.gov/technologies/oil-gas/publications/epreports/shale_gas_primer_2009.pdf

[55] American Petroleum Institute, October 2009, 'Hydraulic Fracturing Operations – Well Construction and Integrity Guidelines', *API Guidance Document HF1, First Edition*. http://www.api.org/~/media/Files/Policy/Exploration/API_HF1.ashx

[56] A tiltmeter is an instrument that measures ultra-long period, angular displacements of the Earth's surface, usually for the purposes of earthquake prediction, and

Schlumberger, 2012, 'Microseismic Hydraulic Fracture Monitoring', *Services & Products*. www.slb.com/services/completions/stimulation/hydraulic_fracture_monitoring.aspx

Computer processing is then used to build a 3D model of the fracturing either post-treatment or in real time.

3.1.2 Well design and construction

High quality well construction is central to successful oil and gas operations in general and to hydraulic fracturing operations. During the construction of a well, a series of steel casings are run into the well and cemented in place in order to isolate the wellbore from the surrounding rock formations and aquifers, and to provide a flow conduit for the production of oil and gas to the surface.

Specially formulated, non-toxic drilling fluids are used when drilling through aquifer zones. These include various bridging agents that minimise fluid losses into the formation.[57] A properly designed drilling fluid will create a thin, impermeable sheath on the wall of the hole, commonly referred to as a 'filter cake'. As the filter cake forms during drilling, an "invasion zone" forms around the well. This zone generally extends a few inches from the wellbore, and has essentially no impact on the groundwater resource.

Following drilling through shallow freshwater aquifers, it is essential to immediately run a pipe through the hole and cement it into place, before drilling ahead with a smaller diameter drill bit. The process of well construction continues, drilling hole sections in stages, with decreasing hole diameter as the depth increases. Each hole section is cased by installing steel pipe that is then cemented in place. In some cases, additional barriers such as external casing packers or swelling elastomers may be used to provide additional hydraulic integrity.[58] By the time the well has reached its final depth and the concentric strings of casing have been installed and cemented, the shallow groundwater aquifer zones will be protected by at least three strings of pipe. The various pipe strings are described below:

> *Conductor casing* is typically the first and largest section of pipe installed and typically extends 20 to 50 metres below ground level. Its primary purposes are to provide an adequate foundation for the well, to prevent the hole collapsing while drilling through any shallow, soft sediments, and to isolate shallow, freshwater zones from the wellbore.

> *Surface casing* is the next section of pipe installed. Its main purpose is to contain any fluids under pressure within the well itself. The setting depth is generally selected based on the deepest known freshwater zones, typically at 400 to 1,000 metres. This string is cemented back to the surface, resulting in a cement sheath between the surface casing and the rock and between the conductor casing and the surface casing. At this point, any shallow aquifer zones above the setting depth of the conductor casing are isolated by two strings of pipe and two cement sheaths.

> *Intermediate casing* is an optional stage of the process that is run if deep, fluid-productive zones need to be isolated from shallow zones, particularly in cases where there is a significant change in formation pressures between zones that could enable crossflow to occur within the open wellbore.[59] In some cases it is possible that multiple sections of intermediate casing may be required. This depends on well depth and geological complexity. If multiple strings of intermediate casing are required, it is sometimes preferable to suspend one or more of the strings from the bottom of the previous string. These suspended strings are then referred to as 'liners'. Regardless of whether an intermediate casing is used, freshwater aquifers are always sealed and protected.

> *Production casing* is the final string installed. It typically runs all the way to the surface (it may also be cemented all the way to the surface). The primary

[57] Typical bridging agents include naturally occurring substances such as calcium carbonate, ground cellulose and mica flakes.

[58] Rigzone, 2012, 'How Does A Swellable Packer Work?', *Training*. www.rigzone.com/training/insight.asp?insight_id=353&c_id=24

[59] Crossflow is the flow of reservoir fluids from one zone to another. The higher pressured reservoir fluid flows out of the formation, travels along the wellbore into a lower pressured formation. (See http://www.glossary.oilfield.slb.com/Display.cfm?Term=crossflow)

purpose of production casing is to isolate the producing zone (oil or gas) from other subsurface formations.

> *Completion tubing* is installed when the well is to be completed as a producing oil or gas well. Various pieces of completion equipment are installed along with the pipe that provides the flow conduit for well production. The tubing is suspended from the wellhead at the surface and is generally installed with a 'production packer' near the bottom to anchor the tubing within the production casing and to provide hydraulic isolation between the tubing and the annulus, and between the tubing and the production casing.

Figure 13 – Well casings

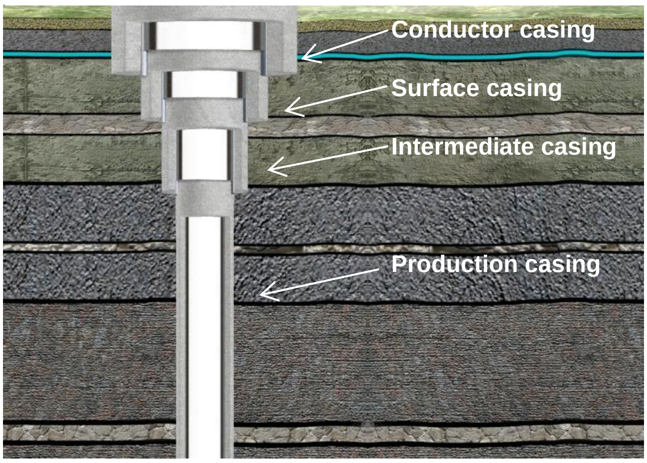
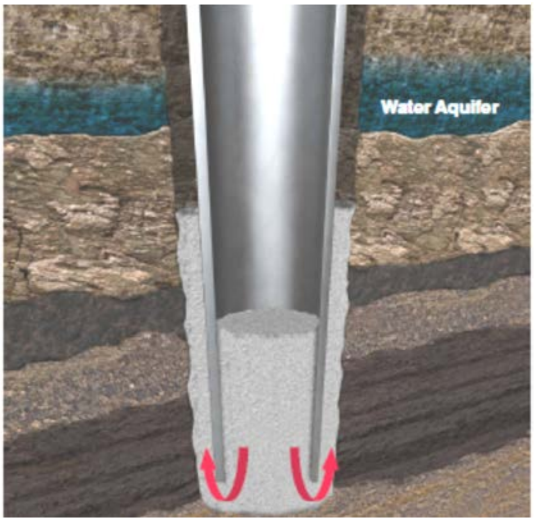


Figure 13 shows the multiple layers of steel and cement used to ensure the aquifers remain protected.[60]

Good cementing techniques are critical for obtaining the desired hydraulic isolation between zones and between the well and the rock formations. Cementing is undertaken by pumping cement slurry down the inside of the casing string and then back up the outside of the casing, as shown in Figure 14. Rubber 'wiper plugs' are used to isolate the various fluid phases and prevent intermixing.

Figure 14 - The process of cementing the well (not to scale)



The cement mixture is designed for the specific conditions of each well. Laboratory testing is undertaken to ensure the cement properties meet the necessary requirements. Special additives are used with Portland-type cement to obtain the desired properties with consideration given to setting time, compressive strength requirements, pumpability and specific gravity.

It is important that the cement fully displaces the drilling fluid in the space between the casing and the exposed rock, without leaving channels that may eventually lead to behind-pipe flow conditions. This is achieved by pumping cleaning pre-flushes, and emplacing the cement under the turbulent flow conditions. It is also desirable to centralise the casing string within the open hole wellbore. This is usually achieved by means of mechanical centralisers which hold the pipe wall off the rock surface to allow good cement coverage around the pipe.

Before drilling out the 'shoe' of the casing for the next hole section, it is necessary to pressure test the casing to ensure hydraulic integrity. The test pressure must be at least as high as the maximum pressure that the casing may be exposed to during subsequent operations.

After drilling is resumed and a short section of new open hole is exposed, a formation integrity test (FIT), sometimes referred to as a 'leak-off' test, is performed.[61] The applied

[60] FracFocus, 2012, 'Drilling and Production', *FracFocus Chemical Disclosure Registry*. http://fracfocus.ca/groundwater-protection/drilling-and-production

pressure at the surface is gradually increased in stages until fluid leakage occurs into the formation. This diagnostic test determines the pressure integrity of the well at the base of the last casing string run. If the pressure integrity is insufficient, remedial cementing may be required, or it may be necessary to run an additional string of intermediate casing, to ensure adequate integrity before drilling into productive formations.

It is not always possible to eliminate fluid losses during drilling. In some cases, such as drilling through naturally fractured or cavernous limestone, large losses of drilling fluid cannot be avoided. However, in these cases it is relatively simple to ensure that freshwater aquifers are not contaminated. This is generally achieved by using fresh water as the drilling fluid, with the application of benign bridging agents such as sawdust, ground gypsum and coconut husks.

Stringent standards are in place for the selection of the steel pipe used for the casing strings and for the cement slurry designs used for each hole section.

Well designs are specific to each location/field and must take account of all well requirements from the initial drilling, to the completion and possible stimulation applications, the producing life, and ultimately the time after the well has finished producing. Stringent standards are in place for the selection of the steel pipe used for the casing strings and for the cement slurry designs used for each hole section. The most commonly used standards in the industry are published by the American Petroleum Institute (API).[62]

A simplified example of a cement bond log is shown in Figure 15 below. Sophisticated computer modelling is used for the selection of pipes and the type of steel used. The modelling considers all scenarios that the well may face. For example, consideration is given to pressures and temperatures, fluid composition and properties, fluid flow rates, imposed mechanical forces, corrosion and erosion, tectonic influences and any other factors that may impact on the long-term integrity of the well. The casing must be able to handle all the forces involved in running the pipe into place (compressive, tensional and torsional forces) as well as the collapse and burst pressures which may be experienced during the various phases of the well's life.[63]

The two main diagnostic tools used are logging tools and pressure testing.

Various tests are undertaken to ensure adequate cement integrity. The two main diagnostic tools used are logging tools run on electric cable, i.e. cement bond logs (CBLs) and temperature logs, and pressure testing. The CBL is an acoustic device that can detect zones of good and bad cement. It operates by transmitting sound waves that are recorded by a receiver within the logging tool.[64] Casing with poor or no cement will show a strong acoustic response (known as "free pipe"). This is similar to tapping the side of a steel drum to determine the fluid level within the drum. If there is a good cement bond between the casing and the formation, the acoustic signal is weak because most of the acoustic energy is absorbed by the formation. More sophisticated logging tools are also available to gather radial data in order to identify channels within the cement.

[61] Wiper Trip, August 2010, 'Procedures for leak-off and limit tests', *Casing Design: Preliminary Design*. www.wipertrip.com/casing-design/preliminary-design/37-procedures-for-leak-off-and-limit-tests-lot-lt-fit.html

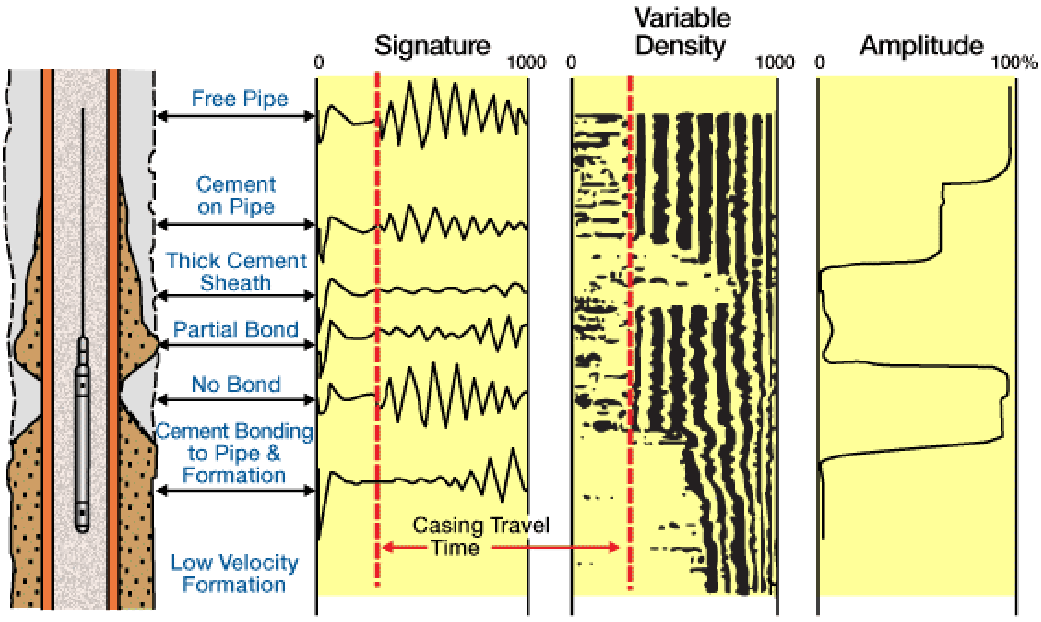
[62] See American Petroleum Institute (API), 2012, 'Publications, Standards, and Statistics Overview', *Publications, Standards, and Statistics*.

http://www.api.org/publications-standards-and-statistics.aspx

[63] Torsional force refers to the stress or deformation caused when one end of an object is twisted in one direction and the other end is held motionless or twisted in the opposite direction.

[64] Bridge7.com, 2012, 'Cement Bond Log CBL-VDL', *Cement Bond Log Interpretation Models*. www.bridge7.com/grand/log/gen/casedhole/cbl.htm

Figure 15 – Illustration of a Cement Bond Log (CBL) [65]



If the logs indicate a poor cement job, it may be necessary to undertake 'remedial cementing'. This may involve pumping additional cement slurry down the casing or perforating the casing and injecting cement into zones of poor cement bonding.

3.1.3 Well perforation

Prior to flowing the well or injecting the fracture fluids into the well, the steel casing is perforated using perforating devices run on wire cable (or coiled tubing). This creates a series of holes or perforations through the wellbore and into the target reservoir formation. In a properly constructed well with good quality cement isolation, the perforations provide the only means for the movement of fluids between the well and the producing formation.

Figure 16 - Photograph of a perforation tunnel in a test slab of rock

Figure 17 - Representation of the process of perforating casing, cement and rock formation (not to scale)

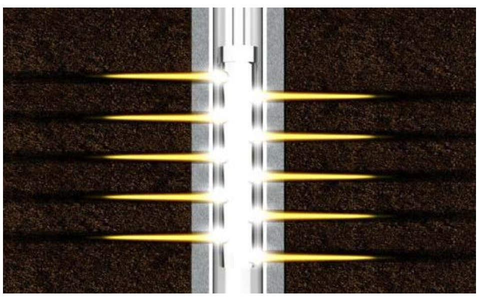


Figure 17 illustrates the perforation process. A special shaped charge is detonated and a jet of very hot, high-pressure gas vaporises the steel pipe, cement, and formation in its path.[66] This creates a series of holes in the casing wall that extend as tunnels through the cement and into the reservoir rock. These tunnels are isolated from each other by the cement similar to Figure 16 above. The producing zone of the reservoir itself is isolated outside the production casing by the cement above and below the zone.

[65] International Petroleum Industry Multimedia System, 'Cement Bond Logging'. http://ipims.com/data/fe11/G40085TA.asp?UserID=&Code=35959

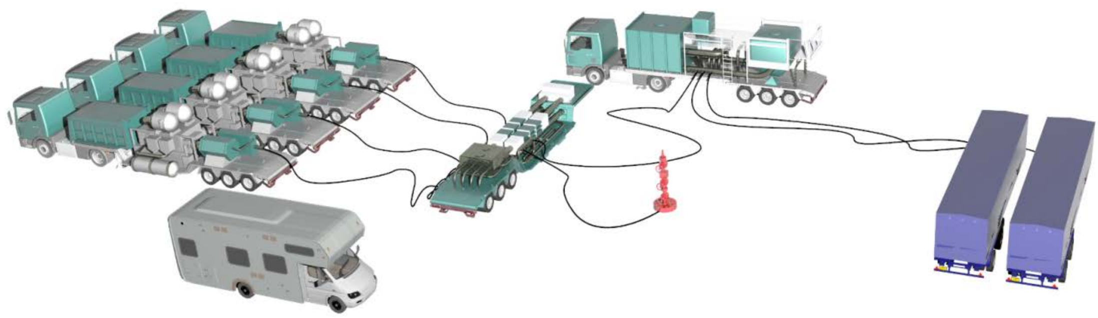
[66] These charges are specifically designed for use in the oil and gas industry, and the associated detonators contain several safeguarding features to ensure safety.

3.1.4 Fracture fluids: pumping and composition

Once the well has been perforated, fracturing fluids laden with proppant are injected under high pressure into the reservoir, creating fractures or fissures.

Blenders mix proppant and chemicals with water to create the fracturing fluid. The water is either sourced from a nearby freshwater source, or from water tanks brought on site for the purpose. Proppant and chemicals are added from specialised holding containers. Pump trucks supply the pressure needed to force the fracturing fluid down the well and create the fractures. The fluids from each pump truck are combined at a treatment manifold, from where they are directed down the well. The operations are monitored and controlled in real time from a control truck (or container) onsite. The key components of the hydraulic fracturing equipment are shown in Figure 18 below.

Figure 18 - Operation set up



When the pumping stops, the hydraulic pressure applied to the formation is released. When this happens, the fractures try to close up due to the in-situ pressures acting on the formation. To ensure the fractures do not completely close, a proppant (propping agent) remains trapped within the fracture and holds the fracture open to create the necessary flow path for the gas and to facilitate long-term production.

Typically, between 97 and 99 percent of the fracturing fluid is water (or brine water) and proppant. Water-based fracturing fluids are specially formulated to transport suspended proppant throughout the entire fracture. The most common proppant is sand that is sieved to a required size range. However, manufactured proppants, such as ceramic beads, are increasingly being used due to their superior strength, size and shape properties.[67]

For the fracturing fluid to have sufficient carrying capacity for the proppant, it is necessary to add gelling agents to the water, the most common being guar gum.

Other additives included in the fracturing fluid prevent clay hydration (absorption of water into clays that then swell and destroy the permeability of the rock), bacterial growth in the fluid, and corrosion of the well equipment. A gel-breaking agent is added so that the fracturing fluid can be flowed back once the well is turned over to production.[68] Chemical additives generally make up one to three percent of the total fracture fluid volume.

Table 1 lists the chemical components of a typical fracturing fluid.

[67] Carbo Ceramics, 2011, 'Why ceramic proppant?', www.carboceramics.com/proppant/

[68] Adapted from Geoglogy.com, 2012, 'Hydraulic Fracturing Fluids - Composition and Additives', Oil and Gas. http://geology.com/energy/hydraulic-fracturing-fluids/

Table 1 - Typical chemicals used in hydraulic fracturing fluids[69]

%	Component	Main Ingredient	Purpose	Common Application
97-99.5%	Water	Water	Main carrying fluid	
	Proppant	Silica sand or manufactured ceramic 'beads'	Keeps fractures open to allow natural gas to flow	
3-0.50%	Gel	Guar gum	Thickens water to suspend the proppant	Thickener in cosmetics, ice cream, toothpaste
	Friction reducer	Polyacrylamide	Minimise friction pressure losses during pumping	Water treatment, soil conditioner
	Crosslinking agent	Borate salts or zirconium	Increase gel viscosity	Laundry detergent, hand soap, cosmetics
	Bactericide	Glutaraldehyde	Eliminates bacteria that may produce corrosive byproducts	Disinfectant, sterilisation of medical and dental equipment
	Breaker	Ammonium or sodium persulfate	Breaks down gel to reduce viscosity	Hair bleaches and hair-colouring preparations
	Corrosion inhibitor	N, n-dimethyl formamide	Prevents corrosion of the steel pipes	Industrial solvent
	Iron control	Citric acid	Prevents precipitation of metal oxides	Food additive, food and beverages, lemon juice
	Clay stabiliser	Potassium or quaternary chloride	Minimise absorption of water into 'swellable' clays	Fertiliser, food processing
	pH adjusting agent	Sodium hydroxide or potassium carbonate	Maintains desired pH for crosslinker effectiveness	Detergent, soap, water softener, glass, ceramics
	Oxygen scavenger	Ammonium bisulfite	Removes oxygen to protect the pipe from corrosion	Fertiliser
	Surfactant	Isopropanol	Enhances water recovery and prevents formation of oil-water emulsions	Glass cleaner, antiperspirant, hair colouring

Historically, service companies have been reluctant to fully disclose the specific chemical compositions of many components used in hydraulic fracturing due to commercial confidentiality. This position has changed, however, and there is a strong move towards total disclosure and the use of non-toxic chemicals that is supported by the oil and gas industry.[70]

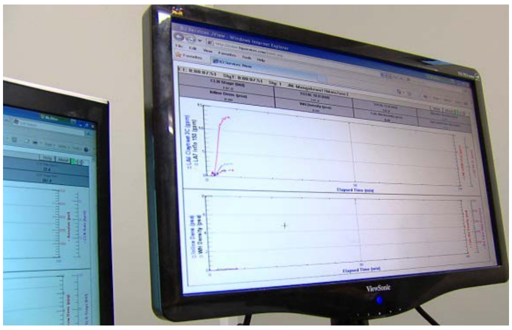
[69] *Ibid*, and

FracFocus Chemical Disclosure Registry, 'What Chemicals Are Used', *Chemical Use*. http://fracfocus.org/chemical-use/what-chemicals-are-used, and

US House of Representatives, April 2011, 'Chemicals used in Hydraulic Fracturing', *Committee on Energy and Commerce*. http://democrats.energycommerce.house.gov/sites/default/files/documents/Hydraulic%20Fracturing%20Report%204.18.11.pdf

[70] See, for example, Canadian Association of Petroleum Producers, January 2012, 'Fracturing Fluid Additive Disclosure'. www.capp.ca/getdoc.aspx?DocId=199626&DT=NTV, and

3.1.5 Fracture formation

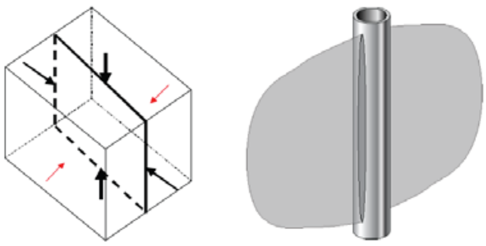


A bi-wing fissure is created emulating either side of the well. The stresses within the formation control the direction and the height of the fracture. The fractures form perpendicular to the direction of minimum principal stress and then propagate in the direction of maximum principal stress.[71]

For typical oil and gas wells that are drilled to several kilometres underground, the minimum stress is normally in a horizontal orientation, as shown in the left side of Figure 19. This means the induced fractures will be vertical. The upward and downward vertical growth of the fracture is usually confined by changes in the geology of the surrounding rock layers, so fractures will then tend to propagate laterally as shown on the right side of Figure 19. Each wing, as shown in Figure 19, grows to a length that is called the fracture half-length and is typically assumed to be symmetric to the well.

The height of the fracture is controlled by variations and interface mechanics between the reservoir layers, the amount of fluid pumped and the state of stress in the formation. For a conventional fracture treatment in a vertical or deviated well, a typical fracture may be 30 to 40 metres in height, but could extend hundreds of metres laterally away from the well.

Figure 19 - Orientation of a vertical fracture relative to the least principal stress direction[72]



Studies have been undertaken to determine the maximum height of fractures created during large-scale high volume hydraulic fracturing operations in US shale gas deposits. The vast majority of fractures were less than 100 metres in height. The tallest fracture recorded during the study was 588 metres. The authors of the study estimate that the probability of a fracture exceeding 350 metres is less than one percent.[73]

3.1.6 Returned fluids

Following the fracturing operations, the fluids from the well are flowed back to the surface where spent fracturing fluids are recovered, usually in lined pits or in steel tanks. The recovered fluids are then safely disposed of through deep well injection, bioremediation on land farms, flaring or recycling. If the well is capable of flow after the treatment, between 25 and 75 percent of the fracture fluids are immediately recovered.[74] The remainder may be slowly recovered during the production life of the well or may remain in the producing formation.

Oil and Gas Financial Journal, 3 December 2010, 'ANGA, IPAA, AXPC support state registry for disclosure of hydraulic fracturing chemicals'. www.ogfj.com/articles/2010/12/anga_-ipaa__axpc_support.html

[71] Nelson, Stephen A., 18 September 2003, 'Deformation of Rock', *Tulane University*. http://www.tulane.edu/~sanelson/geol111/deform.htm

[72] American Petroleum Institute (API), October 2009, 'Hydraulic Fracturing Operations – Well Construction and Integrity Guidelines', *API Guidance Document HF1, First Edition*. www.api.org/policy-and-issues/policy-items/hf/api_hf1_hydraulic_fracturing_operations.aspx

[73] Davies, R.J. et al., 2012, 'Hydraulic fractures: How far can they go?', *Marine and Petroleum Geology*, (Elsevier), Article Number 1575, pp. 1-6. www.dur.ac.uk/resources/dei/JMPG_1575.pdf

[74] Office of Geological Survey Department of Environmental Quality, 31 May 2011, 'Hydraulic Fracturing of Natural Gas Wells in Michigan'. www.michigan.gov/documents/deq/Hydrofrac-2010-08-13_331787_7.pdf

'Returned and produced' fluids from hydraulic fracturing operations include a range of fluids with varying degrees of contamination. The term may include saline formation water that is brought to the surface from a well, often along with oil and gas and, potentially, returned hydraulic fracturing fluids. 'Produced water' is sometimes also used to refer to clean shallow groundwater that is encountered early in the drilling of a well and that might flow to the surface. Methods used to dispose of returned fluids include:

> *Land farming* is a waste disposal technique that has the additional benefit of converting unstable, unproductive sands to fertile pasture, by using natural bioremediation to reduce the concentration of hydrocarbon compounds found in drilling waste and returned fluids.

> *Deep well injection (DWI)* involves pressure pumping waste water down a well and into a specified deep rock formation.

> *Flare pits* provide a controlled environment for the management of well fluids during well control situations, and a safe outlet for potentially highly erosive fluid returns.

> *Recycling* is used in some countries for high volume water hydraulic fracturing operations in shale and coal reservoirs, where very large volumes of water are required and where water supplies may be limited. While this reduces the freshwater volumes required, the remaining, more concentrated fracturing fluids will ultimately need to be disposed of via one of the above methods.

Conclusion

Fracturing operations are undertaken by specialised international oilfield services contractors. Design includes use of highly sophisticated 3D computer modelling simulations to optimise operations and constrain fracture growth.

Well integrity is central to successful oil and gas operations and to hydraulic fracturing. Several layers of steel casing and cement isolate the well from the surrounding rock layers and continuous, rigorous testing ensures well integrity and protection of local freshwater aquifers.

Fracture fluids are injected deep below multiple layers of impermeable rock under high pressure, creating fine fractures and flowpaths for the gas. Growth of the fractures is confined by the geology of the rocks and there is a large vertical distance, usually at least 2,000 metres, between the fracture formation and freshwater aquifers.

Fracturing fluid is typically 97 to 99 percent water and proppant. The remainder is made up of chemical additives, most of which have common applications around the home. Fluids returned to the surface are safely disposed of through consented processes.

CHAPTER 4

Regulatory Environment

This chapter provides an overview of the regulatory environment including the following Acts:

- Resource Management Act 1991
- Crown Minerals Act 1991
- Hazardous Substances and New Organisms Act 1996
- Health and safety regulations.

4.1 Regulatory environment for hydraulic fracturing activities

The regulation of most oil and gas activities is governed by two pieces of legislation, the Crown Minerals Act 1991 (CMA) and the Resource Management Act 1991 (RMA). The CMA allocates the right to prospect, explore and mine Crown mineral resources and provides for financial return to the Crown for those rights. The RMA regulates most of the environmental effects of the petroleum industry onshore and within the territorial sea out to 12 nautical miles. Operators must also comply with all other relevant legislative requirements, including the Hazardous Substances and New Organisms Act 1996 and the Health and Safety in Employment Act 1992.[75]

The following sections describe how each of these Acts controls elements of hydraulic fracturing activities.

4.1.1 Resource Management Act 1991

The RMA establishes the primary control and management of the potential environmental effects of hydraulic fracturing. Regulatory responsibility for granting resource consents authorising hydraulic fracturing operations is split between Regional Councils (e.g. water and air discharges) and District Councils (land use).[76]

Under the RMA, a Regional Council has jurisdiction to regulate, and require resource consents for, the discharge of chemicals into or onto land, air or water, either on the surface or at any relevant depth below the surface. In practical terms this means that a Regional Council may impose consent conditions related to the casing and sealing of all drilled wells that pass through underground aquifers. This means that resource consent requirements or conditions can be imposed on the surface or underground discharge of chemicals and water used in hydraulic fracturing operations.

Taranaki Regional Council requirements

As hydraulic fracturing operations have been concentrated in the Taranaki region, the Taranaki Regional Council (TRC) is the regulatory body that has the most experience regulating hydraulic fracturing operations. The environmental effects of hydraulic fracturing are thus regulated, along with other wellsite activities, under the RMA and the rules in resource management plans prepared by the TRC along with the relevant district authorities. In Taranaki, the TRC prepares the following plans: Regional Fresh Water Plan, Regional Coastal Plan, Regional Soil Plan and Regional Air Quality Plan.

Over the last 10 years the TRC has issued 846 resource consents across the full range of petroleum exploration and production activities from wellsite water takes, to waste treatment and disposal, to land farming and deep well injection, to production station operations and more recently, hydraulic fracturing. The total number of current resource consents held for hydrocarbon exploration and production activities in Taranaki is 692.[77]

Until mid-2011, hydraulic fracturing activities were managed by the TRC as part of general wellsite activities and consenting processes. Under the TRC's Regional Fresh Water Plan (2001) the drilling and construction of an exploration or production well is a permitted activity under Rule 46, subject to the standard terms that all wells must be cased and sealed to prevent the potential for aquifer cross-contamination. The TRC position was that hydraulic fracturing had minimal potential for the generation of adverse effects, given the depth at which the process was undertaken (usually 3,000 metres below ground level), taking into account the geology of the overlying rock formations and that the well integrity provisions of Rule 46 were sufficient to protect freshwater aquifers.

[75] NZ Petroleum & Minerals (MED), 2012, '2012 Block Offer Invitation for Bids'. http://www.nzpam.govt.nz/cms/pdf-library/petroleum-blocks-offers-1/2012-block-offer/2012%20Block%20Offer%20IFB%20June%207%202012.pdf

[76] See Ministry for the Environment (NZ), 2012, 'Resource Management Act'. www.mfe.govt.nz/rma/index.html

[77] Chamberlain, Basil, 19 September 2012, 'Oil and Gas Industry Impacts – A Taranaki Perspective', *Presentation to New Zealand Petroleum Summit.*

Operators still required resource consents for the disposal of drilling wastes and production water, which may have included hydraulic fracturing fluids, via land farms or deep well injection. Operators also required resource consents to flare gas on the wellsite. Thus the majority of activities related to hydraulic fracturing were discretionary activities that required resource consents, although hydraulic fracturing itself did not require resource consents.

To test for any unpredicted environmental impacts and to ensure compliance with consent conditions and requirements, extensive independent monitoring of wellsites in Taranaki has been undertaken by the TRC, including water, soil, physiochemical and biological sampling. In the last 10 years, the TRC has conducted over 700 freshwater bio-monitoring surveys, and over 4,600 water or soil samples, with around 30,000 parameter analyses. There have been over 20,000 recorded interactions with the oil and gas industry as part of the TRC's regulation of the industry.[78]

None of this testing has indicated any adverse environmental effects, including any effects on water quality in freshwater aquifers, caused by drilling or hydraulic fracturing operations.

Following increased public interest about hydraulic fracturing, the TRC sought a legal opinion regarding the consenting of hydraulic fracturing in Taranaki. As a consequence the Council opted to require resource consents for hydraulic fracturing on the grounds that the process constitutes a discharge of contaminants (chemicals, water, proppant) to land, albeit at depth, from an industrial or trade premise as per section 15(1)(d) of the RMA. While the Council's Regional Fresh Water Plan (2001) does not specifically address the activity, a catch-all rule (Rule 44) allows the Council to process hydraulic fracturing discharge applications as a discretionary activity under the RMA, if deemed necessary.

Extensive independent monitoring of wellsites in Taranaki has been undertaken by the TRC.

In July 2011 the TRC advised the petroleum industry that resource consents would be required for hydraulic fracturing. Given an application for hydraulic fracturing at considerable depth would likely meet the "no more than minor adverse environmental effects" and the "no affected party" tests in the RMA, the application could legally and properly be non-notified. The Council decided that although there is public interest in hydraulic fracturing from some groups, this does not mean that these interest groups are affected parties to a resource consent application as recognised pursuant to the RMA.

However, each application would be assessed on a case-by-case basis. In the circumstance where the TRC did assess that there were potentially adverse environmental effects arising from a consent application, then full public notification would be required – together with rights of public submission and appeal to the Environment Court. For example, if hydraulic fracturing was proposed at a shallow depth in very close proximity to aquifers; or where hydraulic fracturing was to be undertaken in different geological conditions where the potential risks of contamination of aquifers were much higher.

Since mid-2011, the TRC has processed 13 consents for hydraulic fracturing activities and these consents have been granted, with conditions, in all instances. Resource consents for hydraulic fracturing related activities have been granted for a variable period (two to five years). They apply to ongoing hydraulic fracturing activities (same well or different wells) at the wellsite, rather than individual hydraulic fracturing events.

The consent conditions are aimed at transparent prior disclosure of information relating to the procedures to be followed, the likely effects, and risk minimisation measures. The resource consents include provisions to protect freshwater resources, such as specifying the minimum depth at which the hydraulic fracturing can occur (generally at or below 3,000 metres), the development and implementation of Monitoring Programmes, and the submission of a "Pre-fracturing Discharge Report" to the TRC before the activity takes place and a comprehensive "Post-fracturing Discharge Report". These reports contain detailed operational diagnostic information used to evaluate the performance and

[78] Chamberlain, Basil, 19 September 2012, 'Oil and Gas Industry Impacts – A Taranaki Perspective', *Presentation to New Zealand Petroleum Summit.*

outcome of a fracturing operation. These reports and measures ensure that the Council has all of the relevant information, including the geotechnical reports of the treatment.

The TRC also administers oil pollution issues on land under delegated authority from Maritime New Zealand. The TRC requires operators, as part of resource consent conditions, to submit comprehensive spill contingency plans aimed at addressing spill emergencies on well sites. Spill contingency plans are in place for each well site and will remain so for the lifetime of the site.

The TRC regulates the discharge of evaporated and combusted returned hydraulic fracturing fluids to the air via flaring. The Regional Air Quality Plan for Taranaki (June 2011) governs discharges to air and sets out the rules for flaring for petroleum exploration and production. As flaring is defined as either a controlled or restricted discretionary activity, resource consents are required and the consents may be publicly notified. The TRC also monitors discharges from flaring. In May 2012 the TRC published its findings on air quality arising from flaring of fracturing fluids, which concluded that there were "minimal effects upon ambient air quality in the vicinity of a flare at which the incidental combustion of hydraulic fracturing fluids was undertaken, in the context of prevailing air quality within the region and nationwide".[79]

Operators also undertake self-monitoring as a component of industry best practice and to provide assurance that consent conditions are being met. Compliance by the oil and gas industry with the conditions of resource consents is generally very high and enforcement interventions are very few, compared with other sectors.

For example, in the last 10 years, the TRC issued 13 abatement notices, nine infringement notices (instant fines) and made two prosecutions against oil and gas companies for more serious breaches of the RMA. Across all resource uses the TRC issued in excess of 1,000 abatement notices, approximately 400 infringement notices and completed 35 prosecutions over the same period.[80]

Land use consents – district councils

Each of the district councils in Taranaki has district plans detailing the policies and rules for activities relating to oil exploration and production.

The New Plymouth District Council District Plan contains the objectives, policies and rules for activities such as building structures, earthworks and the use of hazardous

[79] Taranaki Regional Council, May 2012, 'Investigation of air quality arising from flaring of fracturing fluids – emissions and ambient air quality', *TRC Technical Report 2012-03*, p. 44. http://www.trc.govt.nz/assets/Publications/guidelines-procedures-and-publications/hydraulic-fracturing/Flaring2012-report.pdf

[80] *Ibid*.

substances. Oil and gas exploration, development and production can usually take place within these policies and rules. The plan notes that the established activities of the petroleum exploration and production industry form part of the elements associated with the rural environment.

The Stratford District Plan rules permit certain underground pipeline operations for the distribution of natural gas and petroleum, as well as pre-drilling petroleum exploration activities in the rural zone. Other aspects of petroleum exploration are dealt with as controlled or discretionary activities requiring resource consent.

The council's primary focus is the effect on neighbours and adjacent land uses.

The South Taranaki District Plan has objectives, policies and methods covering a range of issues including the coastal environment, environmental quality, infrastructure, natural hazards, landscape, and historical and cultural heritage. Rules for the rural zone permit petroleum prospecting, including seismic exploration, while petroleum exploration and production testing require resource consent as controlled activities.[81]

Petroleum exploration activities may require land use consents from district authorities. These usually regulate the construction, operation and eventual restoration of the wellsite. The consent authorises the "use and development" of the site for the drilling, well testing (including hydraulic fracturing) and petroleum production activities specified in the consent application. In considering land use consents the council's primary focus is the effect on neighbours and adjacent land uses. Conditions requiring the restoration of land used for wellsites are also included in land use resource consents.

Consent conditions may also impose requirements relating to the submission of a "Hazardous Substances Emergency Management Plan" to the council prior to work commencing, the bunding of tanks and storage areas to prevent leaks and spillages of hazardous substances, notification of spills, and traffic management specified in the District Plan.[82]

4.1.2 Crown Minerals Act 1991

The CMA allocates the rights to explore and develop New Zealand's mineral and petroleum resources. The Minerals Programme for Petroleum 2005 sets out the allocation method and royalties. The Crown Minerals (Petroleum) Regulations 2007 and the Crown Minerals (Petroleum Fees) Regulations 2006 set out the reporting requirements and fees for operators.

The allocation process for petroleum exploration permits is now through block offer bidding. The blocks are awarded on the basis of a work programme detailing the bidder's exploration programmes for the desired block. In New Zealand a work programme may target conventional (including tight resources) and/or unconventional (shale gas, shale oil and coal seam gas) hydrocarbon systems.

In allocating the blocks and awarding the permits, the government takes into account the capability, capacity and competency of the bidders.[83] For example, the 2012 Block Offer required the names, qualifications, professional experience, and length of tenure of the key management staff, and managers in health, safety and environment, geoscience, engineering, research and development. Bidders also had to detail their company's experience, risk management (as defined in AS/NZS ISO 31000:2009 or similar standards) and evidence of their formal internal training or outside training programmes that ensure their staff remain up to date in their area of expertise.[84]

[81] Taranaki Regional Council, February 2009, 'Taranaki Where We Stand: State of the Environment Report 2009', *TRC*, p. 271. http://www.trc.govt.nz/assets/Publications/state-of-the-environment-monitoring/state-of-the-environment-report-200/full+report.pdf

[82] New Plymouth District Council, 2012, 'District Plan Overview', *Plans and Strategies*. www.newplymouthnz.com/CouncilDocuments/PlansAndStrategies/DistrictPlan/DistrictPlanOverview.htm

[83] NZ Petroleum & Minerals (MED), 8 June 2012, '2012 Block Offer Invitation for Bids'. http://www.nzpam.govt.nz/cms/pdf-library/petroleum-blocks-offers-1/2012-block-offer/2012%20Block%20Offer%20IFB%20June%207%202012.pdf

[84] *Ibid.*

Taking these elements into consideration at the allocation stage ensures that all companies operating in New Zealand have sufficient expertise and the resources to explore and develop the petroleum resource in accordance with good industry practice, and can comply with all New Zealand regulations.

In addition to these precautionary safeguards at the permitting stages, the Crown Minerals (Petroleum) Regulations 2007 require operations to be carried out in accordance with recognised good exploration and mining practices and for all activities, including fracturing, to be recorded in the daily well drilling report that must be submitted to New Zealand Petroleum and Minerals.[85]

4.1.3 Hazardous Substances and New Organisms Act 1996

All substances, including hydraulic fracturing fluid, used on a petroleum wellsite are subject to the Hazardous Substances and New Organisms Act 1996 (HSNO). This act is administered by the Environmental Protection Agency.[86] The purpose of HSNO is to avoid or minimise risks to human health and the environment associated with the storage or use of hazardous substances, including hydraulic fracturing chemicals at wellsites.

HSNO sets out the obligations for the handling, storage, use and spill contingencies for hydraulic fracturing fluids. All on-site operations involving hazardous substances are subject to regulations and HSNO requirements, as are well testing operations when significant quantities of flammable or potentially explosive substances are held on site. HSNO controls,[87] together with resource consent conditions as regulated by the TRC, require that the operator of the wellsite has:

All substances used on a petroleum wellsite are subject to the Hazardous Substances and New Organisms Act.

- a register of hazardous chemicals held on site
- copies of HSNO-compliant Safety Data Sheets (SDS) for all hazardous chemicals readily accessible (these contain detailed information on the properties of substances, their safe handling and storage, and how to safely contain and clean them up in the event of a spill)
- identified areas for the storage of chemicals
- Stationary Container Certificates for specific containers (condensate and diesel tanks)
- mandatory separation distances between tanks
- HSNO-compliant signage (site entrance and on tanks)
- an Electrical Wiring Certificate, and
- a Location Test Certificate issued by a registered Test Certifier (effectively certifies that all relevant HSNO requirements have been met).

The operator must also:

- provide secondary containment (120 percent capacity of the largest tank) by constructing bunds around all hazardous substance storage containers and tanks on the site
- provide tertiary containment in the form of a perimeter drain and skimmer pit system that has in excess of 200 cubic metres of containment capacity
- ensure the skimmer pit valve is closed during operations on site
- comply with Level 3 Emergency Management Regulations

[85] Executive Council (NZ), 28 May 2007, 'Crown Minerals (Petroleum) Regulations 2007', p. 71. http://www.legislation.co.nz/regulation/public/2007/0138/latest/whole.html

[86] Ministry for the Environment (NZ), 8 November 2011, 'Hazardous Substances and New Organisms (HSNO) Act 1996', *Laws and Treaties.* www.mfe.govt.nz/laws/hsno.html

[87] *Ibid.*

- ensure that only Approved Handlers handle hazardous substances where this is a requirement of that particular substance, and
- maintain a detailed Spill Contingency Plan for the well site (this must remain in place for the lifetime of the wellsite).

The Environmental Protection Agency has overall responsibility for ensuring compliance with these requirements.

4.1.4 Health and Safety in Employment Act 1992

The Health and Safety in Employment Act 1992 together with associated regulation, Health and Safety in Employment (Petroleum Exploration and Extraction) Regulations 1999, provides detailed requirements for the design, construction and operation (including maintenance) of all petroleum drilling operations (including hydraulic fracturing).

The requirements are administered by the High Hazards Unit of the Ministry of Business, Innovation and Employment (MBIE), which is responsible for health and safety in the petroleum industry. The requirements include obligations to obtain approvals for detailed design and safety evaluations in relation to well integrity and blowout prevention.

While the primary focus of the High Hazards Unit is the health and safety of employees, the independent assessment of well design, construction and operation also provides safeguards with respect to the control of potential environmental impacts or effects due to accidents (e.g. caused by bad well design, malfunction or operational shortfalls) and serves as a second line of independent scrutiny that supplements the assessment of well integrity by the TRC.

Conclusion

New Zealand has a robust, effective regulatory framework in place to ensure hydraulic fracturing operations meet appropriately high safety and environmental standards.

The increased public focus on hydraulic fracturing has already prompted the Taranaki Regional Council (TRC) to review and refine its regulation of hydraulic fracturing operations in Taranaki.

The enhanced regulatory framework, including specific resource consents, compliance requirements, public disclosure of hydraulic fracturing activities, and regulations such as the Hazardous Substances and New Organisms Act 1996 (HSNO), protects the environment and is fit for purpose.

CHAPTER 5

Operations

This chapter provides an introduction to Todd's hydraulic fracturing operations at the Mangahewa field:

> Geology of the Mangahewa field
> Overview of Mangahewa operations
> Industry standards and policies used by Todd
> Todd's health, safety and environment management systems

5.1 Overview of Mangahewa operations

Over the past 10 years Todd has performed a total of 12 hydraulic fracture treatments in five wells, mainly within the Mangahewa field. Three earlier treatments in this field were conducted by the previous operator, Fletcher Challenge, in 1997. The wells and treatment depths are summarised in Table 2. The treatment depths are well below the known freshwater/saltwater interface which occurs at approximately 265 metres below ground level as shown in Figure 20 (page 68).

Table 2 - History of hydraulic fracture jobs undertaken by Todd Energy to mid-2012

Date	Well	Depth Interval mTVD[88]
May 5, 1997	Mangahewa-02	4103-4124
May 21, 1997	Mangahewa-02	3696-3714
May 31, 1997	Mangahewa-02	3590-3608
January 29, 2010	Mangahewa-06	4186-4190
March 5, 2010	Mangahewa-06	4092-4096
March 10, 2010	Mangahewa-06	3933-3936
March 18, 2010	Mangahewa-06	3887-3890
April 28, 2011	Waitui-01	4341-4352
October 21, 2011	Mangahewa-04	4089-4092 4117-4120
November 10, 2011	Mangahewa-04	4059-4062
April 30, 2012	Mangahewa-11	4265-4280 4233-4245
May 4, 2012	Mangahewa-11	4175-4178 4188-4191
May 8, 2012	Mangahewa-11	4103-4117
July 18, 2012	Mangahewa-05	4069-4084
August 4, 2012	Mangahewa-05	3428-3443

Todd is also a partner in the Kapuni field where Shell Todd Oil Services Ltd (STOS) has undertaken 14 hydraulic fracturing jobs between 1993 and 2011. These treatments have also been relatively deep (below 3,300 metres), at an average depth of approximately 3,500 metres, well below the freshwater interface which occurs at around 1,000 metres at Kapuni.

Success developing fields such as Mangahewa means that the same technology can be applied to other discoveries with similar quality gas reservoirs. This in turn creates a larger portfolio of exploration prospects and longer gas independence for New Zealand.

[88] mTVD = metres true vertical depth relative to ground level

Without hydraulic fracturing the level of exploration and production activity would significantly diminish.

5.1.1 Geology of the Mangahewa field

Todd has been actively developing productive gas formations using hydraulic fracturing within the Mangahewa field located near Tikorangi, Taranaki. The Mangahewa wellsites lie in an active petroleum exploration area within the Mangahewa Petroleum Mining Permit 38150. The McKee oil field and the Kowhai and Turangi gas fields are also in the vicinity.[89]

The Mangahewa field consists of relatively deeply buried, stacked, low permeability sandstone gas reservoirs, ideally suited to small scale hydraulic fracturing. To determine the commerciality of the Mangahewa field, Fletcher Challenge (the operator at that time) needed to demonstrate commercial well flow rates from this appraisal well. Three sandstone intervals were initially selected for hydraulic fracturing.[90] Fletcher Challenge first used hydraulic fracturing in May 1997 on the Mangahewa-02 well.

Hydraulic fracturing resulted in a significant improvement in well productivity and a commercial flow of gas.

The appraisal well Mangahewa-02 penetrated a series of fluvial reservoir sandstones in the 1,000 metre thick Mangahewa Formation at depths below 3,300 metres. The sandstones were up to 20 metres thick with average porosities ranging from eight to 11 percent and many zones having very low permeability in the sub-milliDarcy (mD) range. Hydraulic fracturing resulted in a significant improvement in well productivity and a commercial flow of gas. Without hydraulic fracture stimulation, the Mangahewa field might not have been developed.

The Mangahewa Formations are of Eocene age (approximately 30 million years old) and were laid down as a series of fluvial, estuarine and coastal sands, carbonaceous mudstones and coal seams in response to repeated marine transgressions and regressions across the Taranaki Basin. The Eocene and older coals and carbonaceous mudstones are the interpreted source-rock for the Mangahewa field hydrocarbons. Late Eocene muds and silts (Turi Formation) and Oligocene to early Miocene argillaceous limestone, grading above and below into calcareous claystone form an effective local seal to the Mangahewa field.

Above the Otaraoa Formation, 2,500 metres of fine-grained rocks act as a further seal.

The mudstones and siltstones within the thick (200 metres) overlying Otaraoa Formation form the main, regional seal for the hydrocarbon-bearing reservoirs within the Kapuni Group. In addition, minor mudstones and siltstones within the Kapuni Group act as intra-formational seals for the stacked, hydroca rbon-bearing sandstones. Above the Otaraoa Formation is a further 2,500 metres of fine-grained rocks that act as a further seal. The lithologies above the hydraulic fracture zones are set out in Table 3 below.

[89] Todd Energy (Prepared by BTW company), 18 November 2011, 'Resource Consent Application to the Taranaki Regional Council'.

[90] Ministry of Economic Development (Crown Minerals), 24 May 2012, 'Crown Minerals Act 1991: Section 41', *Petroleum Mining Permit 38150*. http://www.nzpam.govt.nz/services-drm-web/RetrieveDocumentServlet.svt?documentId=31AD23DD8FD8B16115CD2CD796DD1692&p_access_no=39D1F2721DD7E4BCE39D4ABB8C37D219

Table 3 - Mangahewa field - Summary of lithologies above hydraulic fracture zones[91]

Formation	Description	Depth (m below MSL)
Egmont Volcanics	River gravels and volcanic debris	Ground Level to +90
Matemateonga (Mat.)	Sandy siltstones and silty claystones	+90 to -350
Urenui (Uren.)	Calcareous claystone with minor interbedded siltstone and sandstone	-350 to -825
Mount Messenger (Mnt. M)	Claystone with very fine and fine sandstone beds	-825 to -1400
Manganui	Claystone with minor sandstone, siltstone and limestone beds	-1400 to -2925
Taimana	Calcareous claystone grading into argillaceous limestone	-2925 to -3075
Tikorangi	Argillaceous limestone	-3075 to -3125
Otaraoa	Calcareous silty claystone with minor calcareous siltstones	-3125 to -3325
Turi	Argillaceous, carbonaceous siltstone	-3320 to -3325
Mangahewa	Quartz sandstone	-3400 to -4400

The reservoirs that have been subjected to hydraulic fracturing treatment in the Mangahewa field belong to the Mangahewa Formation and the underlying Kaimiro Formation. These formations occur at depths of approximately 3,400 to 4,400 metres below ground level, as shown in the above litho-stratigraphic chart (Table 3). The formations consist of hydrocarbon and water-bearing sandstones separated by mudstones, siltstones, shale and coals.

5.1.2 Location of the Taranaki aquifer

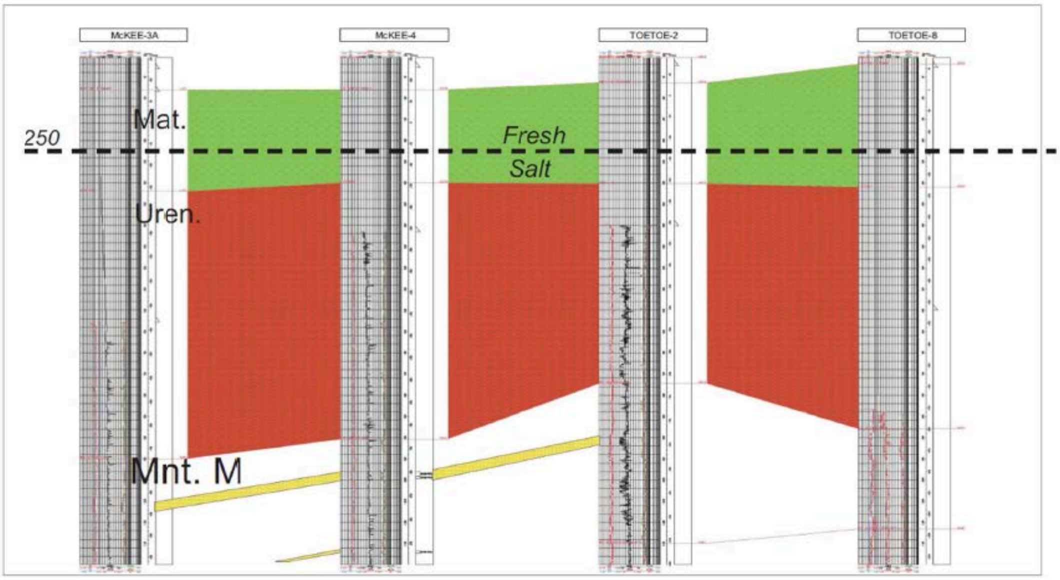
Most modern wells in the greater Mangahewa area do not record the saline-freshwater interface on the upper hole section where the transition occurs, since the hydrocarbon-bearing zones are much deeper, typically below 3,000 metres. Work undertaken by Petrocorp in 1997 concluded that the interface was at 130 metres below sea level.[92] STOS did a review in 2004 using some of the McKee field wells and concluded that the interface was between 50 to 150 metres below sea level.

The interpreted interface in both Mangahewa and McKee wells approximates to the mid-Matemateonga Formation which varies between 125 metres and 275 metres below sea level. The lower part of the Matemateonga and all formations below this stratigraphic horizon are saline, as shown in Figure 20.

[91] Consent 7971-1, 11 April 2012, 'Pre Fracturing Discharge Report - Mangahewa-11 well'.

[92] Internal Petrocorp Report

Figure 20 - McKee field cross section – freshwater-saline water interface[93]



The Mangahewa C wellsite is 135 metres above sea level which puts the interface at around 265 metres below ground level. The zones into which the fracturing fluids are discharged have been demonstrated to provide containment, as they are over-pressured relative to hydrostatic pressure. This means that the seals above (the Otaraoa Formation) are very effective. Within the reservoir section there are also smaller, intra-formational seals.

5.1.3 Scale and practice

Unlike the large scale hydraulic fracturing processes used in shale gas, Todd's operations are relatively small scale, using much less water and equipment, and over a shorter period of time. On a geological scale the pressures and induced fractures are minor. The cracks created are approximately 500 metres long but they are only between two and seven millimetres wide and along a small vertical plane of approximately 20 to 40 metres.

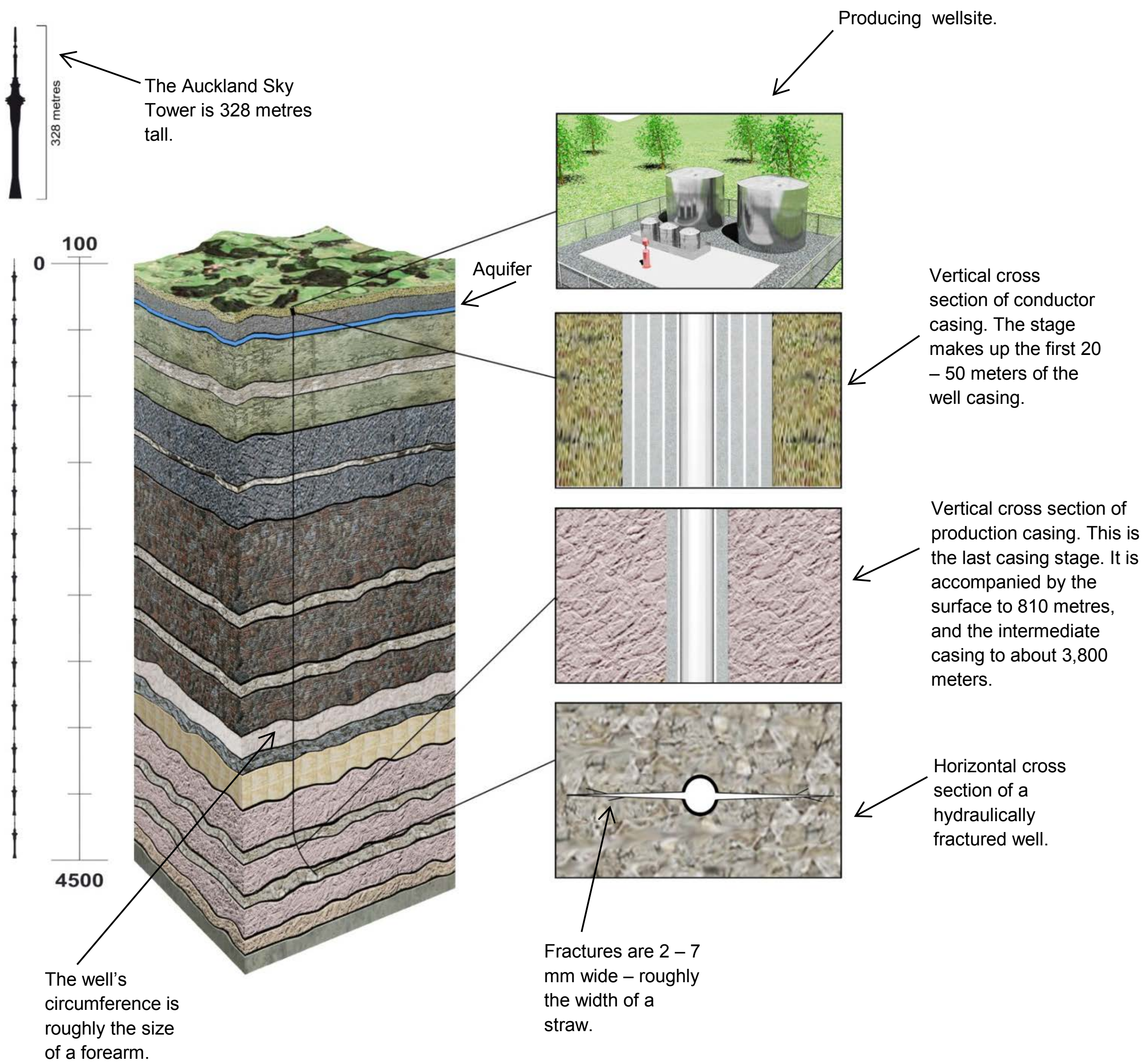
Figure 21 provides a scale of Todd's operations compared to the Sky Tower. The other breakout boxes to the right (from top to bottom) are illustrations of a completed wellpad, multiple casings protecting fresh water aquifers, production casing and a fracture (as viewed from above the wellbore).

Todd uses industry best practice, and its well construction and operations meet the Health and Safety in Employment (Petroleum Exploration and Extraction) Regulations 1999 as well as Todd's health, safety and environmental policies. A typical Mangahewa gas well completion is depicted in Appendix D, alongside which is the pore pressure and fracture gradient pressure profile vs depth for a Mangahewa well.

Todd contracts the hydraulic fracturing operations to Baker Hughes. Baker Hughes is an international oil service provider with extensive experience in hydraulic fracturing.

[93] Todd Energy, 11 April 2012, 'Consent 7971-1 Pre Fracturing Discharge Report - Mangahewa-11 well'.

Figure 21 - Cross section of a hydraulically fractured well



Planning and design

Todd's planning of a hydraulic fracturing treatment includes a comprehensive assessment of safety, environmental and commercial factors alongside the technical detail required to undertake the activity successfully. Computer modelling, which uses log derived rock properties as key input, creates simulations of the hydraulic fracture treatment. The simulations generate proppant concentration diagrams which graphically illustrate the lateral and vertical extent of the induced fracture and the concentration of proppant within the fracture. These models are calibrated with the results of the treatment to optimise future operations.

Todd currently uses the services of Barree & Associates,[94] an industry leader in the field, located in Denver, Colorado to undertake this modelling. Barree use an in-house 3D modelling software called GOHFER to design and optimise the hydraulic fracture treatments. The key objectives for the design are to:

> optimise the lateral extent of the propped fracture

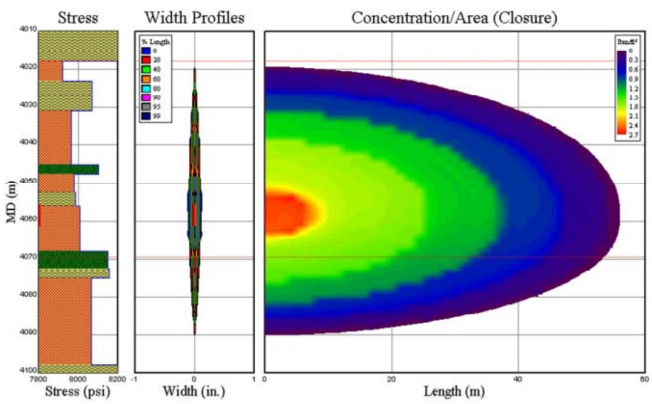
> maximise the flow conductivity of the propped fracture

> minimise the volume of fluids and proppant pumped, and

> minimise the risk of fracturing into adjacent saltwater-bearing zones (limit vertical growth of the fracture).

Figure 22 is an example of a job design for Mangahewa-04. The display on the right shows the proppant concentration (pounds per square feet) as a function of depth (Y-axis) and distance from the well (X-axis) with the brighter colours indicating higher proppant concentration (and wider opening) compared to the darker colours towards the end of the propped fracture.

Figure 22 - Managahewa-04 Proppant Concentration Diagram[95]



[94] Barree & Associates, 2012, 'Consulting Services'. http://barree.net/Consulting.html

[95] Todd Energy (Prepared by BTW company), 18 November 2011, 'Resource Consent Application to the Taranaki Regional Council'.

[95] Adapted from: Todd Energy, 2012, 'Waitui-1 Testing Stage 2A –MaA1 DFIT and Frac'.

5.1.4 Composition of Mangahewa hydraulic fracturing fluid

While most of the additives used in fracturing fluid are ingredients found in many common household products and foods, in a pure or concentrated form, some of the chemicals used are toxic. Prior to use in fracturing, the chemicals that are classified as hazardous substances are significantly diluted and are used in accordance with the manufacturer's instructions, and in compliance with the HSNO and any relevant district or regional council consents. The majority of the fluid eventually returns to the surface for carefully controlled disposal at a consented facility. Any fracturing fluids that are left in the reservoir are trapped in situ, unable to reach the surface and unable to enter potentially usable groundwater.

The composition of the hydraulic fracturing fluid typically used in the Mangahewa wells (Baker Hughes' "SpectraFrac G" fluid system[96]) is shown in Table 4 below. Product names in brackets are those used by Baker Hughes.

Table 4 - Mangahewa field - Hydraulic fracturing fluid composition[97]

Function	**DFIT Fluid**	**Pad Fluid** (SpectraFrac G without proppant)	**Frac Fluid** (SpectraFrac G with proppant)	**Displacement Fluid**
Base fluid	3% KCl water	3% KCl water	3% KCl water	3% KCl water
Surfactant (Inflo 150)	0.1 vol%	0.1 vol%	0.1 vol%	0.1 vol%
Bactericide (Magnacide 575)	0.005 vol%	0.005 vol%	0.005 vol%	0.005 vol%
Clay stabilizer (Claymaster 5C)	0.1 vol%	0.1 vol%	0.1 vol%	0.1 vol%
Buffer (BF-7L)	0.5 vol%	0.5 vol%	0.5 vol%	0.5 vol%
Gelling agent (GLFC-5L)	0.875 vol%	0.875 vol%	0.875 vol%	0.875 vol%
Crosslinker (XLW-56)	-	0.4 vol%	0.4 vol%	-
Gel breaker (HP-CRB)	0.05 lb/Mgal	0.05 lb/Mgal	0.4 lb/Mgal	0.05 lb/Mgal
Scale Inhibitor (Scaletrol 720)	0.1 vol%	0.1 vol%	0.1 vol%	0.1 vol%

The proppant used is 20/40 "Carboprop"[98] (small, manufactured, ceramic balls like very uniform grains of sand) with one percent by weight of ScalSorb-3 (a solid scale inhibitor) mixed into it. In the final stages of fluid pumping, seven percent by weight of FlexSand HS (resin coated aluminium needles) is added to minimise proppant back-production during flowback and long-term production. As noted earlier, additives generally make up less than three percent of the total volume of the fluid. The remaining 97 to 99 percent is clean water and proppant. The proppant, and any fluids which do not return to the surface, will remain below the sealing layers.

[96] Baker Hughes, 2010, 'Environmentally Responsible Fracturing Technology', *Achieve environmental goals without sacrificing well performance.* http://public.bakerhughes.com/shalegas/collateral/31070.Environmentally%20Responsible%20Fracturing%20flyer_11.10B.pdf

[97] Todd Energy (Prepared by BTW company), 18 November 2011, 'Resource Consent Application to the Taranaki Regional Council'.

[98] Carbo Ceramics, 2011, 'Carbo Prop'. www.carboceramics.com/CARBO-PROP/

The chemical composition of the hydraulic fracturing fluid pumped down the well changes over time. The degree of alteration depends on the degradation properties of the chemicals concerned, the temperature and chemistry of the reservoir, interactions with reservoir fluids, and the nature of the rock matrix.[99] Some chemicals are preferentially absorbed by the reservoir. Other components in the hydraulic fracturing fluids react with the polymer to reduce the apparent viscosity. Some polymers are immobilised on the fracture wall as a high viscosity film.

5.1.5 Todd's management of returned fluids

During Todd's hydraulic fracturing operations, returned fluid that is or may be contaminated with hydrocarbons or returned hydraulic fracture fluids, is treated as wastewater. Fluids are moved from the well to storage via steel lines which have been pressure tested. The fluids are stored in bunded tanks on site, for as short a time as possible (for storage space reasons), typically less than two days. It is then trucked off site, analysed and disposed of, according to the terms of the relevant resource consents.

Where water is produced during production from a well, this is piped, together with the oil and gas, to a production station to be separated and disposed of. Todd uses both land farming and deep well injection (DWI) under the terms of resource consents for disposal of produced formation water and returned fluids. Waste water analyses from Todd hydraulic fracturing operations are included in Appendix F.

Fluids are moved from the well to storage via steel lines which have been pressure tested.

Todd does not recycle returned fluids. Given the small scale of hydraulic fracturing activity, the abundance of water supplies in Taranaki, the relatively small amount of fluid used in conventional deep hydraulic fracturing operations, the availability of suitable DWI wells, and taking account of environmental footprint and economic considerations, Todd does not see this as an appropriate method of treating returned fluids from its hydraulic fracturing operations at this time.

The environmental effects and risk mitigation of Todd's disposal methods are detailed further in Chapter 6.

5.1.6 Comparison of pre-fracture and post-fracture well performance

In many cases, it is possible to compare well performance (primarily gas productivity) before hydraulic fracturing and after hydraulic fracturing in order to quantify the benefits and apply the results to future operations. As hydraulic fracturing costs millions of dollars per application, the benefits must justify the costs.

For technical, logistical and cost reasons, not all prospective zones are flow tested before being hydraulically fractured, particularly where the rock properties of the prospective zone can be compared to an analogous zone elsewhere that had been flow tested prior to stimulation. In addition, data is available from the Diagnostic Fluid Injection Test (DFIT) which gives a reasonable indication of permeability by observing and analysing the rate at which pressure dissipates when the pumping ceases. If the fluid pressure decline is very slow, this is an indication of low permeability. Table 5 is a summary of flow rate data from a number of wells (operated by Todd or STOS) where pre- and post-fracture data is available. In all cases, there was a major improvement in well productivity.

[99] 'Rock matrix' refers to the fine grain material of a rock in which larger bodies or grains may be set, also known as ground mass.

Table 5 - Comparison of pre- and post-frac flow data (Todd Energy and STOS operated wells)

Well	Zone	Pre Frac Rate (MMscf/d)	Post Frac Rate (MMscf/d)	Comments
Mangahewa-02	G	-	-	10-fold increase
Mangahewa-06	A1	No flow	5	
	A3	6	>20	
	A4	No flow	3	
Mangahewa-04	MaA1	0.5	3.5	Rate impaired by water production. Potential for 7 MMscf/d after remediation
Mangahewa-11	MaA5	1	5.5	Rate impaired by water production. Potential for 11 MMscf/d after remediation
Waitui-1	MaA1	No flow	0.2	
Kapuni-04	K1B	0.9	5.3	
Kapuni-06	K3A	8.8	21	"Skin frac"
Kapuni-08	K1A	7	14	"Skin frac"
Kapuni-15	K1A	11	32	"Skin frac"

MMscf/d = million standard cubic feet per day

5.2 Todd's standards, practices and policies

Todd has maintained an excellent safety and environmental track record in its hydraulic fracturing operations. It has achieved this through meeting international industry best practice, New Zealand regulations and its commitment to robust world-class health, safety and environment (HSE) management systems.

Professor Rosalind Archer of the University of Auckland has assessed Todd's operations against international examples and best practice and found that Todd's operations "do not pose health, safety or environmental risks that are in anyway unacceptable or inappropriate". Professor Archer's full submission is attached as Appendix H1.

5.2.1 Industry best practice

Todd's drilling programmes meet the requirements of the Health and Safety in Employment (Petroleum Exploration and Extraction) Regulation 1999. This requires that all onshore operations be conducted in accordance with the 'Institute of Petroleum Model Code of Safe Practice in the Petroleum Industry, Part 4, Drilling and Production Safety Code for Onshore Operations 1986' (the Code).[100] Relevant codes of practice, specifications and standards that are applicable include the following American Petroleum Institute (API) Recommended Practices:

API RP 49	Recommended Practice for the Safe Drilling of Wells Containing Hydrogen Sulphide
API RP 53	Recommended Practice for Blowout Prevention Equipment Systems

[100] New Zealand Government, 'Health and Safety in Employment (Petroleum Exploration and Extraction) Regulation 1999' *Schedule 1 Part 1-4*. http://legislation.knowledge-basket.co.nz/gpregs/text/1999/349/349_an.html

API RP 9B	Recommended Practice for the Application, Care and Use of Wire Rope for Oilfield Service

Where the guidelines in the Code are superseded and/or are not applicable, Todd uses the relevant specifications, standards and recommended practices provided by the API to ensure that well activities are conducted in accordance with generally accepted and appropriate industry practice. API provides an extensive range of continually updated specifications, standards and recommended practices for the oil and gas industry globally.[101]

Specifically for hydraulic fracturing operations Todd adheres to the following industry guidance documents:

API HF1	Hydraulic Fracturing Operations-Well Construction and Integrity Guidelines[102]
API HF2	Water Management Associated with Hydraulic Fracturing[103]
API HF3	Practices for Mitigating Surface Impacts Associated with Hydraulic Fracturing[104]

The following are examples of API specifications, standards and recommended practices adopted by Todd for casing and tubular design:

API Spec 5B	Specification for Threading, Gauging and Thread Inspection of Casing, Tubing and Line Pipe Threads
API Spec 5B1	Recommended Practice for Gauging and Thread Inspection of Casing, Tubing and Line Pipe Threads
API Std 65-2	Isolating Potential Flow Zones During Well Construction
ANSI/API Spec 6A	Specification for Wellhead and Christmas Tree Equipment
RP 5C1	Recommended Practice for Care and Use of Casing and Tubing
Spec 5CT	Specification for Casing and Tubing

Where API standards are superseded, other industry bodies are used to ensure well activities are conducted in accordance with generally accepted and appropriate industry practice. An example of this relating to casing design is the following standard from the International Organization for Standarization (ISO):

ISO 10400 TR	Petroleum and natural gas industries – Casing, tubing and drill pipe – Equations and calculations for performance properties

As part of the well design and operations, Todd currently contracts Halliburton to provide cementing services. As part of the Halliburton Management System the design and operating of cementing activities are compliant with the following standards:

API Q2	Specification for Quality Management System Requirements for Service Supply Organizations for the Petroleum and Natural Gas Industries
API RP 75/75L	Guidance Document for the Development of a Safety and Environmental Management System for Onshore Oil and Natural Gas Production Operations and Associated Activities
API RP Q1	Specification for Quality Programs for the Petroleum, Petrochemical and Natural Gas Industry

[101] For a complete list of API publications, refer to: www.api.org/publications/

[102] American Petroleum Institute, October 2009, 'Hydraulic Fracturing Operations—Well Construction and Integrity Guidelines', *API Guidance Document HF1 First Edition*. www.shalegas.energy.gov/resources/HF1.pdf

[103] American Petroleum Institute, June 2010, 'Water Management Associated with Hydraulic Fracturing', *API Guidance Document HF2 First Edition.* www.shalegas.energy.gov/resources/HF2_e1.pdf

[104] American Petroleum Institute, January 2011, 'Practices for Mitigating Surface Impacts Associated with Hydraulic Fracturing', *API Guidance Document HF3 First Edition*. www.shalegas.energy.gov/resources/HF3_e7.pdf

ISO 14001	Environmental management systems requirements with guidance for use
ISO 9001	Quality Management Systems – Requirements
OSHA 18001	Occupational Health and Safety Zone

Additional guidance documents for cementing include:

RP 10B-2/ISO	Recommended Practice for Testing Well Cements
TR 10TR1	Cement Sheath Evaluation

In anticipation of offshore drilling activities, Todd is currently preparing a Drilling Management System (DMS) document which will supersede its Onshore Drilling Procedure Manual and be used and maintained as its sole DMS.

5.2.2 Todd's health, safety and environment management system

Management of Health, Safety and Environmental issues (HSE) is an integral and essential part of the way Todd conducts business. Todd's track record reflects its commitment to robust, world-class HSE management systems, utilising international industry best practice, and employing the highest quality staff and industry contractors. The Health, Safety and Environmental Management System (HSE MS) follows the requirements as specified in the Todd Corporation HSE MS, which provides the foundation for consistent deployment of HSE standards across the Todd Group of Companies. Todd's corporate Health and Safety and Environmental policies are appended as Appendix D.

Todd's incident management system fosters an open and positive incident reporting culture with its service providers.

Todd's HSE MS is built on a series of interlinking systems, which supports a work culture to deliver:

- zero injuries
- zero environmental incidents
- zero non-compliance issues, and
- continual HSE improvement.

Todd Corporation's HSE MS takes a structured approach to managing business activities using an integrated methodology built on a platform of the following recognised national and international standards:

ISO 9001	Quality Management System (QMS)
ISO 14001	Environmental Management System (EMS)
AS/NZS 4801	Occupational Health and Safety Management System (OSH MS)
NZS 7901	Safety Management System for Public Safety (SMS PS)

The HSE MS consists of 21 Systems, each of which incorporates the underlying principles and expectations to be met in the design, construction, maintenance and operation of Todd's facilities and assets.

HSE Performance

Todd has delivered strong HSE performance with its fracturing operations. Incident statistics from 2010 onwards are set out in Table 6 below.

Table 6 – Todd HSE performance history

WellSite	Lost Time Incident	Medical Treatment Case	First Aid Case	Environment-Low Potential Minor Events	Near Miss
Mangahewa-06	0	1	3	2	3
Waitui-01	0	0	0	3	0
Mangahewa-04	0	0	0	3	1
Mangahewa-11	0	0	1	0	1

Note: Todd defines a near miss as any incident that did not result in injury or loss but had the potential to do so had conditions been slightly different. Reporting and learning from near miss incidents provides the opportunity to make changes to prevent a reoccurrence that could result in more serious consequences. Having a highly developed incident reporting culture is therefore an integral part of best practice HSE management.

One (the only) TRC consent breach occurred at Mangahewa-06 on April 2010, when Todd did not notify residents within 1,000 metres of the site at least 24 hours in advance before flaring operations occurred. Todd has since enhanced its community relations and communications strategies to ensure this does not occur again.

Training and competency

Todd is a highly competent and experienced operator. In addition to proficiency gained through undertaking hydraulic fracturing operations in Taranaki, all of Todd's senior managers and many of its staff have extensive international experience in oil and gas exploration including hydraulic fracturing operations. Todd's HSE MS ensures that all employees and contractors meet its stringent standards.[105] Todd also ensures that all staff and contractors are adequately skilled to undertake hydraulic fracturing (see Appendix B: Todd Competency Profile). If the necessary skills cannot be sourced in-house, Todd engages international expertise. Todd contracts Baker Hughes, a specialist oilfield services provider based in Houston, Texas, to perform the hydraulic fracturing treatments at Mangahewa. Baker Hughes operational personnel have advanced competency-based training, extensive international experience, and comply with international industry best practice and all local regulatory requirements (see Appendix C. Baker Hughes Profile).

Todd's track record reflects its commitment to world-class HSE systems and international best practice, and employing the highest quality staff and contractors.

Incident management

As noted above, Todd has a strong, established incident management system, which fosters an open and positive incident reporting culture with its service providers. All incidents or near misses at the workplaces are recorded and reported via Todd's Incident Reporting & Investigation System. This is a formal system whereby all HSE incidents are:

> recorded

> assigned a degree of risk rating

[105] Todd Corporation, 2012, 'Health, Safety & Environment'. http://www.toddcorporation.com/content/health-safety-environment

> immediately reported upwards to senior managers
> investigated
> necessary remedial actions are taken (e.g. adjustments to processes, equipment), and
> then closed out through a weekly management incident review forum.

Risk management

Todd's risk management with regard to hydraulic fracturing starts with comprehensive reservoir analysis and feasibility studies, combining geological features, rock properties, offset well experiences, regulatory guidelines, and economic drivers to support a team of expert engineers. This includes:

> efficient well placement across the field to maximise reservoir drainage and improve water management logistics
> proper well construction to ensure zonal isolation for the life of the well
> extensive rock property data gathering (including logging and coring)
> optimised hydraulic fracture stimulation treatments to responsibly maximise production and economic returns
> enhanced recovery technologies to delay production declines and extend well life, and
> safe and effective plugging and abandonment procedures at the end of the well's productive life.

Risk management is a fundamental principle for the safe execution of fracturing from design through to completion. Todd applies a systematic approach to the identification, assessment and control of risk, commencing with hazard identification and analysis studies at the design phase. Engineering controls are utilised widely and in particular on pumping and surface equipment as part of the controls to maintain integrity of pressure containing equipment.

On site a range of administrative risk management tools are employed to control hazards such as Permit to Work, Job Safety Analysis, Pre-Job Safety Meetings, and Behaviour Based Safety processes.

5.2.3 Community engagement

In addition to the potential environment effects, hydraulic fracturing and other wellsite operations may also impact local communities. Sensitivity to and mitigation of these effects is a critical part of good industry practice.

Todd recognises that it relies on the good will and support of local communities for its social licence to operate.

Todd has been operating in Taranaki for over 50 years and prides itself on the strong relationships it has built with the people of Taranaki. The company consults regularly with local communities and affected groups, and works to understand and acknowledge their needs and sensitivities, and keep them up to date with its plans.

Todd has a Community Relations Manager based in Taranaki who works closely with a range of stakeholders and community groups through a detailed ongoing engagement programme. The programme's goal is to ensure local communities are fully informed about Todd's proposed operations and are not negatively affected by those operations.

Todd regularly publishes and circulates consultation documents and hosts community meetings in areas where development is proposed.

Todd has a Māori and iwi engagement programme in Taranaki, aimed at building more enduring relationships and a better understanding of iwi and hapū concerns and aspirations in Taranaki.

In line with its Operating Principles, Todd recognises that it relies on the good will and support of local people for its social licence to operate, and also seeks to demonstrate this by making a positive contribution to the communities in which it operates. This involves a range of engagement activities, such as supporting local schools and hosting stakeholders at community functions held in conjunction with the annual WOMAD (World of Music and Dance) festival. Todd is also a principal sponsor of the WOMAD festival.

Todd provides at least 24 hours' notice to local residents who live within a 1,000 metre radius of an operation as to when flaring of fluids and gas will be taking place. Todd also provides these residents with a 24 hour phone line so they can ring Todd if they have any concerns. It maintains a record of all queries and complaints received.

Todd's New Plymouth District Council land use consent sets noise limits for Todd's wellsites, and these are carefully observed. Todd also keeps truck traffic off the road during school bus times and during junior rugby at the local rugby club on Saturday morning, to help ensure the safety of the community.

In addition to establishing and maintaining relationships with the community Todd sponsors a number of events and activities in Taranaki and New Zealand. Further information on these is detailed in Chapter 7.

Conclusion

To date, Todd has performed 12 hydraulic fracture treatments in Taranaki.

Todd uses low volume conventional fracturing, typically in sandstones below 3,000 metres, with multiple overlying layers of seal rocks. The risk of contaminating a shallow freshwater aquifer (at around 400 metres below ground level) or surface water during such treatments is significantly lower than in high volume water fracturing used in shallow, shale gas developments in the United States.

Hydraulic fracturing is an essential technology for the development of the low quality reservoirs of the Mangahewa gas field. Without hydraulic fracturing Mangahewa and other similar fields would not be economic to produce.

Todd's excellent safety and environmental track record has been achieved through meeting international industry best practice, commitment to world-class health, safety and environmental management systems, and employing the highest quality staff and contractors. Its hydraulic fracturing operations will continue to be developed and refined through a process of continuous improvement.

Todd recognises that it relies on the goodwill and support of local people for its social licence to operate and it prides itself on the strong relationships it has built in the communities in which it operates.

CHAPTER 6

Potential Environmental Effects and Mitigation

This chapter details the potential environmental impacts and how they are mitigated generally and in Todd's operations:

> Protection of freshwater aquifers
> Fluids composition and chemical handling and storage
> Water management
> Safe management of returned fluids
> Air emissions
> Noise
> Seismic activity
> Emerging technology

6.1 Protection of freshwater aquifers

A key requirement for any onshore oil or gas development is the protection of shallow groundwater resources from possible contamination by chemicals used in the drilling and completion of exploration and production wells. This issue has received significant public attention in recent years in the United States particularly with regard to the use of hydraulic fracturing in shale gas and CSG developments.

There are four possible means by which shallow freshwater aquifers could be contaminated with fracturing fluids:

> *Well integrity failure:* This could occur if there are multiple failures in the tubing and casing strings and the cement between them, allowing wellbore fluids to be injected directly into the aquifer zone. However, the chance of this happening in a properly constructed well is extremely low, given the number of casing strings and cement sheaths isolating the fracture fluid from the aquifer zone during treatment operations.
>
> Extensive well integrity testing is undertaken immediately before fracturing fluids are pumped. In addition, the pressures in the annuli[106] between the various pipe strings are constantly monitored during pumping operations. Any sudden change in annulus pressure could signal a failure in well integrity at which point the pumping operation would be stopped immediately.

> *Fracture extending into aquifer zone:* When undertaking hydraulic fracturing operations in relatively deep rock formations, for example, at depths greater than 500 metres below the deepest aquifer zone, the probability of fractures extending into the aquifer is very remote. Even for large-scale hydraulic fracturing operations undertaken in shale gas formations, it is rare for a fracture height to exceed 350 metres.[107] Todd performs relatively small fracture treatments which create long lateral fractures with a height of 20 to 40 metres at the most.
>
> The height of the fracture treatment is controlled by many factors including the geology of the reservoir, the amount of fluid pumped and the state of stress in the formation. Fracture design simulations are carried out to predict the growth and extent of induced fractures. The models used for the simulations are then calibrated with actual field results to improve the accuracy of predictions for future jobs in nearby wells.

> *Behind-pipe flow:* Fluids could potentially escape between the cement and rock outside of the multiple casing strings if there is poor cement bonding between the casing and the formation. For this to occur, however, there would need to be multiple failures in the cement bonding between the target zone and the aquifer.
>
> The various pressure integrity tests undertaken during the drilling operation (including cement bond logging) ensure that adequate integrity has been developed from the multiple cement jobs. Again, the likelihood of water contamination occurring due to a 'behind pipe-flow' scenario is extremely low, especially as the Diagnosis Fluid Injection Test (DFIT) will reveal if the localised cement bond is inadequate (in which case remedial action is taken or the main fracture cancelled).

> *Surface spillage:* This could occur at various stages during the fracturing operation, including transport and materials handling during job preparation, leakage from pipes or tanks during the pumping operation, and leakage of returned fracturing fluids into the ground during flow back operations. Surface spillage is the most likely scenario by which groundwater aquifers could be contaminated with fracturing fluids.

[106] The space between two concentric pipes where fluid can flow, such as between casing and tubing. The pipe may consist of drill collars, drillpipe, casing or tubing. (See http://www.glossary.oilfield.slb.com/Display.cfm?Term=annulus).

[107] Davies, R.J. et al., 2012, 'Hydraulic fractures: How far can they go?', *Marine and Petroleum Geology*, (Elsevier), Article Number 1575, pp. 1-6. www.dur.ac.uk/resources/dei/JMPG_1575.pdf

An important step in any drilling operation, not just in hydraulic fracturing, is to obtain baseline data of water composition from any sources which could be affected, such as rivers, lakes and groundwater aquifers. If subsequent testing reveals changes to water composition, this data can be used to identify the existence and source of potential contamination. Because the chemicals used in the fracturing operation are known, it is possible to determine if contamination was caused by a loss of fracturing fluids into a groundwater aquifer.

An important step in any drilling operation is to obtain baseline data of water composition.

As discussed in Chapter 5 hydraulic fracturing operations in Taranaki are generally undertaken at much greater depths than the fresh water aquifers. There have been no documented cases of contamination of fresh water aquifers due to drilling or hydraulic fracturing operations in Taranaki.

6.1.1 Mitigation of risks – well design and construction

The primary means of protecting groundwater is through proper well construction. The report on hydraulic fracturing by the UK Royal Society and Royal Academy of Engineering released in June this year[108] noted that the likelihood of well failure for shale gas developments in the United Kingdom is low if wells are designed, constructed and abandoned in line with best practice standards.[109]

An example of the monobore[110] well design for Todd's Mangahewa-11 well is shown in Figure 23. Key features of the design include:

- conductor casing (13-3/8") set at 50 metres, cemented to surface
- surface casing (9-5/8") set at 810 metres, well below the freshwater interface, cemented to surface
- intermediate casing (7") set at 3,813 metres, above the natural gas productive zones, cemented to inside the 9-5/8" surface casing[111]
- production casing (4-1/2" liner) set at 4,776 metres, across the gas productive zones and cemented to the inside of the 7" intermediate casing
- production tubing (4-1/2") attached to the top of the production casing and fixed in place with a tubing anchor. The tubing is made of special corrosive resistant alloy (13Cr), and
- a fail-safe Tubing Retrievable Sub-Surface Safety Valve (TRSSSV) included in the production tubing.

With this design, any shallow freshwater zones are protected by three strings of pipe and the cement sheath between the 9-5/8" surface casing and the surrounding rock formations. In addition, there are two annuli which can be monitored during stimulation operations. A sudden change of annulus pressure would signal the loss of well integrity, enabling the pumping operation to be stopped immediately, virtually eliminating the risk of injecting contaminants into an aquifer zone.

Any shallow freshwater zones are protected by three strings of pipe and the cement sheath.

Constant pressure monitoring during fracturing operations ensures that any pressure losses or pressure increases are quickly identified by the specialists on site (the frac master, engineer and client representative) and addressed. Todd provides pre and post-fracturing reports to the TRC to communicate the safeguards used as part of the hydraulic fracturing operation.

[108] The Royal Society and The Royal Academy of Engineering, June 2012, 'Shale gas extraction in the UK: a review of hydraulic fracturing', *United Kingdom.* http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/projects/shale-gas/2012-06-28-Shale-gas.pdf

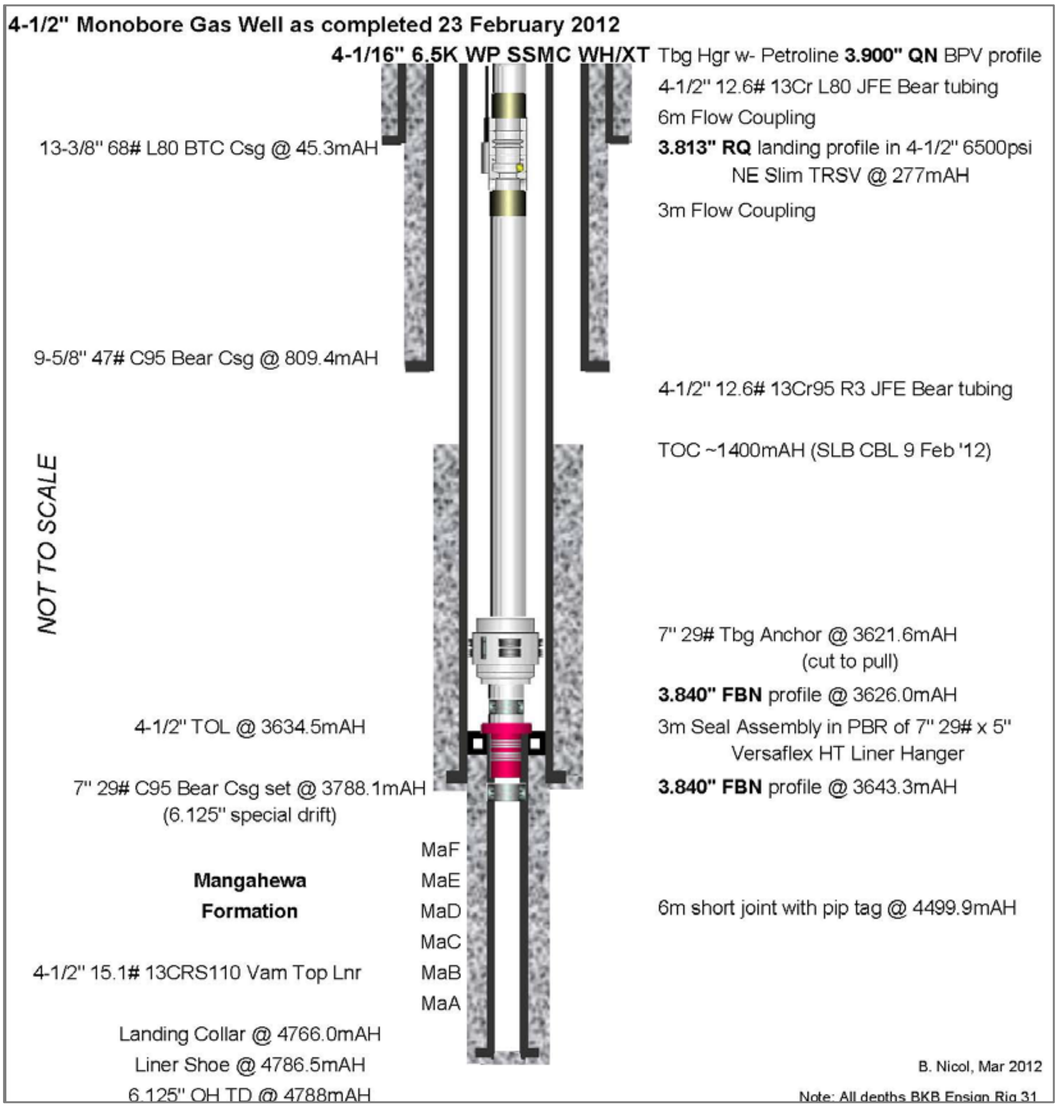
[109] *Ibid,* p. 4.

[110] A monobore design uses production tubing with the same inside diameter as the production casing. This type of design enables smaller diameter casings to be used instead of running the tubing *inside* the production casing.

[111] At times losses are experienced while cementing, thus this objective, despite using special lightweight cement, is not always fully achieved. As there are not hydrocarbon bearing intervals in this hole section this is not a problem.

Wells are specifically designed (confirmed by pressure testing) to withstand high reservoir pressures (up to ~7,000 psi) as well as the pressures associated with hydraulic fracturing. All annuli are equipped with pressure monitoring equipment. If pumping pressures reach a pre-set level (around 7,000 to 8,000 psi), the pumping system high pressure limit set point will be reached and the pumping stopped.

Figure 23 - Managahewa-11 well schematic



A typical Mangahewa gas well completion is depicted in Appendix E, alongside which is the pore pressure and fracture gradient pressure profile vs depth.

In 2011, the TRC undertook an assessment of the hydro-geological risks associated with the practice of hydraulic fracturing of hydrocarbon reservoirs in Taranaki.[112] This was updated in 2012 and reviewed by GNS Science. The overall conclusion was that there is little risk to freshwater aquifers from properly conducted hydraulic fracturing operations in Taranaki. The report makes it clear what is meant by "properly conducted" operations.

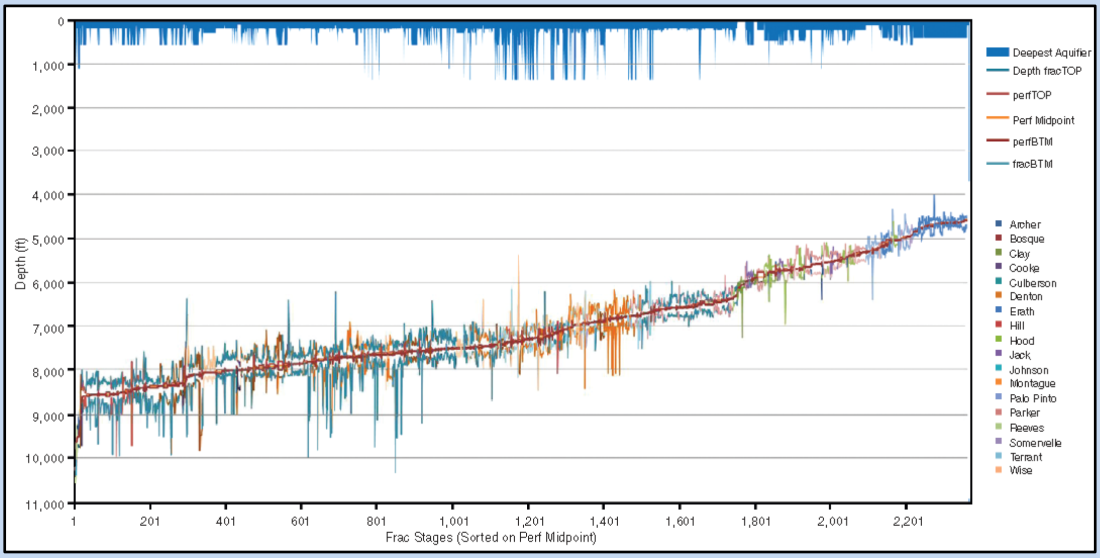
[112] Taranaki Regional Council, 17 February 2012 , 'Hydrogeologic Risk Assessment of Hydraulic Fracturing for Gas Recovery in the Taranaki Region'. http://www.trc.govt.nz/assets/Publications/guidelines-procedures-and-publications/Fresh-water-2/fracking-report-feb2012.pdf

6.1.2 Case study: Monitoring of the Barnett Shale in the United States

As previously discussed the risk of the fractures extending into aquifers is very low. The Barnett Shale provides a case study of the size of fractures across multiple fracture treatments.

Figure 24 below shows the monitoring of hydraulic fracturing undertaken in the Barnett Shale reservoir in the United States where more shale gas hydraulic fracturing operations have been mapped than in any other reservoir. The chart shows data collected on thousands of hydraulic fracturing treatments in the Barnett Shale in the Fort Worth Basin in Texas and illustrates the fracture top and bottom for all mapped treatments performed since 2001. Importantly, the chart shows the significant distance between induced fractures and fresh water aquifers. The microseismic and tiltmeter technologies used to monitor the treatments are well established, and are also widely used for non-oil field applications such as earthquake monitoring, volcano monitoring, civil engineering applications, carbon storage, and waste disposal. Extensive mapping of hydraulic fracture geometry has been performed in North American shale reservoirs since 2001.[113]

Figure 24 - Barnett Shale mapped fracture treatments (TVD) [114]



The depths are in true vertical depth. Perforation depths are illustrated by the red-coloured band for each stage, with the mapped fracture tops and bottoms illustrated by coloured lines corresponding to the counties where they took place.

The deepest water wells in each of the counties where Barnett Shale fractures have been mapped[115] are illustrated by the dark blue shaded bars at the top of Figure 24. As illustrated in the figure, the top of the largest directly measured upward growth of all of these mapped fractures is still several thousand feet below the deepest known aquifer level.

6.2 Fluids handling and storage

6.2.1 Transport and storage

Chemicals are transported to the wellsite in containers specifically designed to minimise the release of chemicals in the case of an accident. At the well site, the chemicals are stored in containers specifically designed for the physical and chemical properties of

[113] FracFocus, 2012, 'Hydraulic Fracturing: The Process', *FracFocus Chemical Disclosure Registry*. http://fracfocus.org/hydraulic-fracturing-how-it-works/hydraulic-fracturing-process

[114] Fisher, Kevin, July 2010, 'Data Confirm Safety of Well Fracturing', The American Oil & Gas Reporter, Pinnacle: A Halliburton Service, p. 1. http://www.halliburton.com/public/pe/contents/Papers_and_Articles/web/A_through_P/AOGR%20Article-%20Data%20Prove%20Safety%20of%20Frac.pdf

[115] Refer to: United States Geological Survey, http://nwis.waterdata.usgs.gov/nwis.

each particular chemical. In addition, secondary containment facilities are used to protect against contamination in the unlikely event of a chemical spill.

The risks of surface spillage are not confined to hydraulic fracturing operations. The risk is present throughout drilling operations, as it is for any industrial activity involving the transport and storage of chemicals. Contingency measures are in place so that any spilled liquids are contained within the well site and quickly recovered for later disposal. Todd also voluntarily bunds storage areas for dry chemicals held on its wellsites. These operations conform to the RMA consents and HSNO regulations and requirements detailed in Chapter 4: Regulatory Environment.

In addition to the possibility of accidental spills or leakage from piping or tanks, it is possible that recovered liquids may enter the ground at the surface during flowback. Flowback might involve flowing the well to a 'flare pit' where the accompanying gas is flared until the well is sufficiently cleaned up to place it on normal production. During this operation, the flowback water may accumulate in the flare pit and could enter the ground if the pit is not adequately lined. Todd undertakes well flowback operations using a pressurised separator vessel so that the gas is separated from the liquids before being flared. The separated liquids are then recovered and stored in tanks for later disposal. Note: the management of flare pits is discussed in more detail in section 6.5.2.

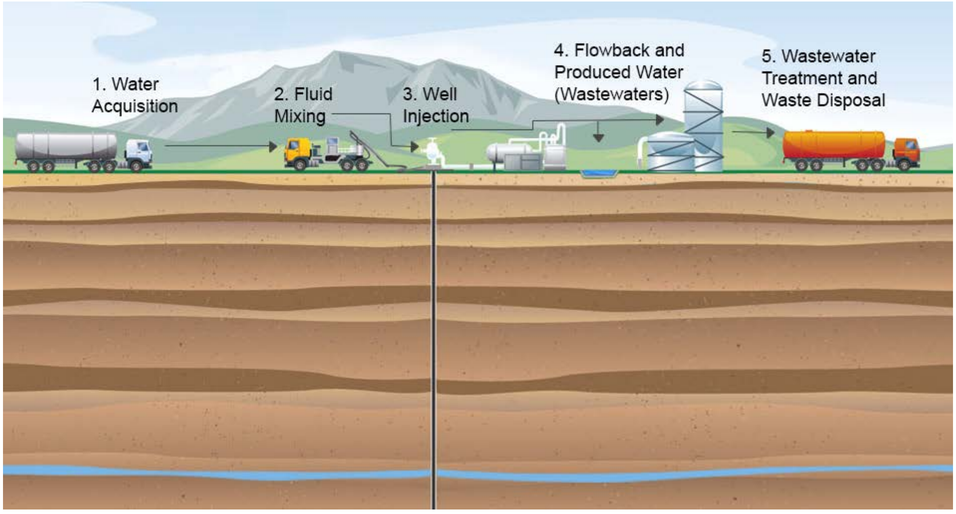
6.3 Water management

Proper management of water from initial sourcing through to ultimate disposal (or re-use) is a key part of the hydraulic fracturing process.[116] As with the issue of protection of freshwater resources, water management has received considerable public attention, primarily because of the very large volumes of water required for shale gas developments in the United States and elsewhere, including Australia.[117] In some locations, the availability of fresh water supplies is limited and supplies that are available may be required for other competing uses such as agriculture or domestic consumption.

The volume of water used in conventional hydraulic fracturing operations in Taranaki is much smaller than is used in shale gas operations, and supplies are plentiful.

The diagram below illustrates the water cycle for hydraulic fracturing operations.

Figure 25 - The water cycle in hydraulic fracturing operations[118]



[116] American Petroleum Institute, June 2010, 'Water Management Associated with Hydraulic Fracturing', *API Guidance Document HF2 First Edition.* www.shalegas.energy.gov/resources/HF2_e1.pdf

[117] US Department of Energy, April 2009, 'Modern Shale Gas Development in the United States: A Primer', (prepared by Ground Water Protection Council). http://www.netl.doe.gov/technologies/oil-gas/publications/epreports/shale_gas_primer_2009.pdf

[118] Adapted from: US Environmental Protection Agency, 2012, 'The Hydraulic Fracturing Water Cycle'. http://www.epa.gov/hfstudy/hfwatercycle.html

6.3.1 Source, use and treatment of water (industry wide)

The industry acquires fresh water from a number of sources, including:

> surface water from streams, rivers, lakes

> groundwater from freshwater aquifers

> recycled water from flowback operations

> desalinated brine water (from producing oil and gas wells, subsurface aquifers and seawater), and

> wastewater from other industries (such as CSG production).

In some instances, depending on compatibility with the treatment additives and the rock formations being stimulated, it may be appropriate to use brine water (including seawater) instead of freshwater.[119]

There are no issues in Taranaki concerning competition for access to water between industry, agriculture and domestic use.

The form of transport required depends on available infrastructure, potential environmental effects and the distance from the water source to the wellsite. In some cases, water (such as surface water, bore water or recycled water) is retrieved from local supplies at the wellsite. This allows in-field pipelines and pumps to be used and means minimal transport is required. In other cases, water is retrieved through pipelines (either dedicated or shared with other users), or is trucked to the site using tankers.

Onsite storage generally consists of lined, excavated pits or water tanks.

The mixing of the water with the chemical additives is generally done at the wellsite. While some of the chemical additives may be pre-mixed, the actual fracturing fluid is mixed as the treatment is pumped down the well.

6.3.2 Taranaki operations (Todd specific)

Water use by Todd and other operators is strictly controlled by the TRC. Resource consents are required to use local water resources and limits are set on maximum daily withdrawals. At some wellsites, the water can be drawn from nearby streams. For example, the TRC granted a Water Permit to Todd for the Mangahewa-D wellsite allowing up to 100 cubic metres of water to be taken from the Manganui River per day. In other cases, water may need to be trucked in and stored on site. Taranaki has a good supply of freshwater and there are no issues concerning competition for access to water between industry, agriculture and domestic use.

The TRC monitors farm and domestic bores within a 2.5 kilometre radius of wellsites.

Recent hydraulic fracturing operations have been undertaken at the Mangahewa C wellsite (which is within the Waiau catchment), using water from a small, nearby, unnamed tributary of the Waiau River. There are no groundwater bores within one kilometre of the wellsite (as recorded in the TRC's "Regional Xplorer" database).

6.4 Safe management of returned fluids

A large proportion of the fluids that are pumped into the well are returned to the surface during the flowback stage. Initially these fluids are normally dominated by the composition of the displacement fluid, with fluids later in the clean-up flow containing more polymer. Later in this process, formation fluids normally begin to dominate the clean-up flow. If formation water has been intersected in the fracturing process, this too can become part of the returned fluid.

[119] Schlumberger, 2009, 'Technical Paper: Successful Multistage Hydraulic Fracturing Treatments Using a Seawater-Based Polymer-Free Fluid System Executed From a Supply Vessel; Lebada Vest Field, Black Sea Offshore Romania', *Abstract*. http://www.slb.com/resources/technical_papers/technical_challenges/unconventional_gas/121204.aspx

Depending on the means of subsequent disposal, some form of treatment of the returned fluid may be required. Treatment could involve one or more of the following processes:

> solids removal (e.g. gravity settling, hydrocyclone separation or filtration)
> desalination
> removal of fracturing fluid chemical additives
> removal of naturally occurring chemicals "leached" from the rock formation, and
> removal of hydrocarbons and other compounds resulting from contact with oil and/or gas produced from the treated formation.

Depending on the level of treatment and the chemical composition of the treated wastewater, options for disposal include:

> injection into deep disposal wells (typically into salt water aquifers or depleted hydrocarbon reservoirs)
> land farming
> recycling for use in fracturing fluids, and
> evaporation (with separate disposal of residual solids).

6.4.1 Treatment of returned fluids in Todd operations

The total volume of fluids pumped down the well during the Waitui-1 well workover was approximately 1,626 cubic metres (all zones combined). The total volume recovered was 1,326 cubic metres, indicating that about 80 percent of fluids returned to the surface.

During flowback, the well stream is diverted through a 'sand catcher' and a three-phase separator. The gas is flared in a lined flare pit and the liquids are recovered and stored in tanks ready for subsequent disposal.

There are two authorised waste disposal methods in Taranaki – land farming (through BTW Company Ltd under consent 7884-1) or deep well injection (DWI).

As part of the waste disposal, Todd's waste water is independently analysed. Appendix F details three representative analyses of Todd waste water.

6.4.2 Land farming

Todd contracts with BTW Company for land farming services for solid wastes generated during drilling or well stimulation activities. BTW operates a number of land farming sites in Taranaki. The waste from Todd is transported to the Brown Road Land Farm where it is placed in a dedicated storage pit. The landscape is initially prepared by scraping back and stockpiling the existing topsoil and levelling out the uneven ground. The waste is then distributed over the prepared area, mixed in with the soil and allowed to dry sufficiently before being tilled into the soil. The disposal area is then levelled and the previously stockpiled topsoil is applied to a thickness of 200 millimetres to aid stability and assist in grass establishment. Fertiliser is then applied and once the disposal is complete, the area is sown as pasture and available to be used for grazing.

As well as increasing land stability, fertility and ecological productivity, this bioremediation technique increases microbial activity, water retention and farming potential.

Figure 26, below, shows the Brown Road Land Farm before land farming and seven months after land farming.

Figure 26 – Brown Road pre land farming (left) and 7 months later post land farming (right)

Prior to 2011, specific resource consents for the disposal of hydraulic fracturing fluids were not required by the TRC. In May 2011, however, the TRC advised all hydrocarbon exploration operators that the disposal of wastes arising from hydraulic fracturing would have to be explicitly consented, as it had been determined by the Council that "fracking wastes" could not be included within the definition of "drilling wastes" as the activity giving rise to them was a distinct activity.[120]

BTW subsequently lined two of the site storage pits with polythene, so that the fluids could be temporarily stored without becoming a discharge to land. BTW lodged application 6815 on 14 June 2011 for a new land farming consent which would include drilling waste, oily waste, condensate storage tank wastewater, and well work-over fluids, including fracturing fluids. The consent (7884-1) was subsequently granted.

The TRC resource consent conditions for the Brown Road facility, referred to above, require:

> notification to the TRC (48 hours in advance) of the type and volume of waste to be stored at a site

> notification to the TRC (48 hours in advance) of intent to spread wastes including the type, volume and concentrations of hydrocarbons in the waste, and the specific location and areas in which the waste will be applied

> sampling of wastes and analysis for specified chemicals including BTEX (benzene, toluene, ethylene and xylenes), polycyclic aromatic hydrocarbons (PAHs), ethylene glycol and gluteraldehyde. Results are to be provided to the TRC prior to discharging the wastes

> record keeping and reporting on specified parameters

> specific storage methods

> specific constraints on the rate of application of wastes

> no discharge within 25 metres of surface water courses

> pasture establishment and monitoring (following application of wastes), and

> receiving environmental limits – upper limits on the permissible concentrations of specified substances able to occur in water and soil as a consequence of land farming.

The resource consents for land farming also involve ongoing monitoring and chemical analysis of soils used in the process to ensure there are no negative environmental effects. The sites are monitored after one, three, six, nine and 12 months and then

[120] Taranaki Regional Council, March 2012, 'BTW Company Limited Brown Road Landfarm Monitoring Programme Annual Report 2010-2011: Technical Report 2011–60', p. 19. http://www.trc.govt.nz/assets/Publications/technical-reports/oil-and-gas-compliance-monitoring-reports/987702w.pdf

annually until the consent is surrendered. The following analyses are required under the TRC's consent conditions:

> hydrocarbon content
> salinity (chloride concentration)
> conductivity
> sodium concentration
> BTEX, and
> naphthalene, pyrene, benzo (a) pyrene.

In addition to conforming to the TRC's consent conditions, BTW has undertaken various initiatives over and above the consent requirements, including:

> development of a Geographic Information System database
> installation of groundwater bores for water quality monitoring
> initiation of mushroom experiments[121]
> involvement in TRC/LandCare NZ research into worm/nematode health, and
> marine intertidal surveys.

The TRC's annual report on the Brown Road Land Farm covering the year from 2010-2011 found that BTW demonstrated an overall high level of environmental performance and compliance with the resource consent. There were no incidents recorded by the TRC that were associated with consented activities at the site.[122]

6.4.3 Deep well injection

Todd holds resource consents from the TRC to dispose of hydraulic fracturing wastes (along with produced water, drilling fluids, and contaminated stormwater). DWI involves pressure pumping the waste down a well and into a specified deep rock formation.

Conditions on the resource consent issued by TRC include:

> submission of an Injection Operations Management Plan to the TRC that includes operational details of the injection activities, identification of the conditions that would trigger concerns about the integrity of the injection well, injection zone or overlying geological formations, and actions to be taken if trigger conditions are reached
> provision of specified information relating to maintenance of well integrity, confirmation of the depth of freshwater and chemical analysis of the receiving/formation water
> the specified maximum pressure of the wellhead
> the specified rate and volume of injection
> the specified receiving rock formation and minimum depth of injection
> the keeping of specified records (injection pressure, maximum and average rate of injection, volume injected)
> the type, source and chemical composition of the fluids
> a "Monitoring Programme" (of specified content) aimed at assessing the effects of the exercise on freshwater resources, to be certified by the Chief Executive Officer for the TRC prior to the exercise of the consent

BTW demonstrated an overall high level of environmental performance and compliance with the resource consent.

[121] Terranova, Luz Gracew, 2011, 'The Intelligence of Mushrooms in Environmental Restoration', *Reality Sandwich.* www.realitysandwich.com/intelligence_mushrooms_environmental_restoration

[122] Taranaki Regional Council, March 2012, 'BTW Company Limited Brown Road Landfarm Monitoring Programme Annual Report 2010-2011: Technical Report 2011–60', p. 19. http://www.trc.govt.nz/assets/Publications/technical-reports/oil-and-gas-compliance-monitoring-reports/987702w.pdf

> detailed analyses of freshwater samples for specified parameters
> the submission of a Sampling and Analysis Plan to the TRC for certification, and
> annual reporting that includes the provision of an (updated) Injection Modelling Report illustrating the ability of the receiving formation to continue to accept additional waste fluids, and estimating its remaining storage capacity.

The TRC publishes reports on the monitoring of deep well injection processes.[123]

Todd supports the use of DWI for the disposal of fracturing fluids provided the disposal wells used are carefully selected, i.e. the same rigour is applied as for the selection and use of produced water disposal wells. Based on sample analysis it is clear that returned fluids have a lower environmental impact than produced water, which is normally very saline, and typically contains traces of residual hydrocarbons and production chemicals (e.g. corrosion inhibitors and biocides). For that reason, Todd believes that, in principle, disposal of returned fluids together with produced water is good practice.

Notwithstanding this, Todd does not inject returned fluids with its produced water; instead, it injects these fluids into the watered-out McKee oil reservoir (through McKee-1). Todd has selected this reservoir for its proven seal integrity and because these sandstones contain considerable volumes of residually trapped waxy oil. Reservoir management considerations mean this approach is not suitable for the produced water. The volumes of fracture fluids involved are small enough (on a reservoir scale) to allow small variations from the optimum reservoir management approach.

6.4.4 Purification and recycling

Todd does not see recycling as an appropriate method of treating returned fluids from its hydraulic fracturing operations at this time. This reflects the small scale of its hydraulic fracturing activity, the abundance of water supplies in Taranaki, the relatively small amount of fluid used in conventional deep hydraulic fracturing operations, the availability of suitable DWI wells, and taking account of environmental footprint and economic considerations.

6.4.5 Discharge of emissions

During Todd's hydraulic fracturing operations, in the early phases of production testing of a well, fracturing fluids and any entrained solids (such as proppants) are returned to the surface where they are passed through a sand filter (to remove solids) and a three-phase, gas/liquid separator. Hydraulic fracturing fluids are thereby recovered, stored in tanks on the wellsite and trucked away to waste disposal.

However, under some circumstances, for safety or equipment protection reasons or in emergency situations, there may be a need to "temporarily" discharge the initial return fluids to the lined flare pit (with gas) where they are evaporated and/or combusted. Flaring of gas is regulated by the Crown Minerals (Petroleum) Regulations 2007[124] and by the TRC Regional Air Quality Plan for Taranaki.[125]

Emissions and flaring of gas are discussed in the following section.

6.5 Air emissions

The issue of air emissions arising from hydraulic fracturing operations has received much attention in the United States due to the recent increase in shale gas developments. The primary concerns are around the release of:

[123] Taranaki Regional Council, 2012, 'Oil and gas compliance monitoring reports'. http://www.trc.govt.nz/oil-and-gas-compliance-monitoring-reports/#oil

[124] New Zealand Parliamentary Counsel Office, 2012, 'Crown Minerals (Petroleum) Regulations 2007', *New Zealand Legislation.* http://www.legislation.co.nz/regulation/public/2007/0138/latest/DLM438040.html

[125] Taranaki Regional Council, July 2011, 'Discharges from industrial or trade premises or industrial or trade processes (excluding waste management processes)', *Regional Air Quality Plan for Taranaki*, p. 64. http://www.trc.govt.nz/assets/Publications/regional-air-quality-plan/air-plan-index/raqp-rules1-29.pdf

- volatile organic compounds (VOCs)
- toxic air emissions, and
- methane.

VOCs are released to the atmosphere through the process of evaporation. They have a high vapour pressure at room temperature conditions as a result of their liquid forms having a low boiling point. Many VOCs released as a result of industrial activities are harmful to human life as well as being the main contributor to the formation of ozone (smog) in cities. During hydraulic fracturing operations, VOCs are released from engine exhausts (as with all petrol or diesel engines) or may be released due to vaporisation of hydrocarbon liquids e.g. evaporation of gas condensate from atmospheric-pressure storage tanks.

Toxic air emissions are those which are hazardous to health or which may cause adverse environmental effects. Examples include benzene (found in petrol vapours or vaporised condensate) and heavy metals such as mercury or lead.

Methane is not toxic but is a potent greenhouse gas. The direct radiative effect of methane is about 20 times stronger than carbon dioxide over a 20-year time frame.[126] Release of methane into the atmosphere is also a waste of natural resources.

A typical Mangahewa well clean-up flow takes only one day.

Sources of air emissions arising from hydraulic fracturing operations include:

- exhaust emissions from diesel engines (generators, compressors, pumps, trucks)
- combustion products from the flaring of hydrocarbons (primarily the burning of gas)
- fugitive emissions (emissions of gases or vapours from pressurised equipment due to leaks), and
- venting of gases and vapours from atmospheric-pressure tanks or at the flare pit (if no ignition)

Because of the large number of shale gas wells drilled and hydraulically fractured in the United States, their collective contribution to air emissions is significant.[127] To reduce emissions during hydraulic fracturing operations, the US Environmental Protection Agency (EPA) has issued rules requiring operators to capture natural gas rather than venting or flaring it through the use of so-called "green completions".[128] Shale gas wells typically require three to 10 days of flowback to clean up the well prior to putting it onto permanent production through a gas-gathering system. It is this flowback period which is the subject of the move towards green completions.

6.5.1 Management of flaring operations by Todd Energy

As noted earlier, the scale of individual hydraulic fracturing operations in Taranaki is much smaller than shale gas operations in the United States. A typical Mangahewa well clean-up flow takes only one day and very few wells are hydraulically fractured each year compared to a full-scale shale gas development. Nevertheless, air emissions are still a concern and are addressed when planning and undertaking any hydraulic fracturing operation (or indeed any wellsite operation which results in the release of contaminants into the atmosphere).

Todd's current practice is to separate out fluids before flaring the natural gas (as outlined earlier), enabling cleaner combustion than if the full well stream is sent to the flare pit. However, under emergency conditions it may be necessary to divert the full well stream

[126] US Environmental Protection Agency, 1 April 2011, 'Methane', *Climate Change*. www.epa.gov/methane/

[127] US Environmental Protection Agency, 18 April 2012, 'Oil and Natural Gas Air Pollution Standards', *Air and Radiation*. www.epa.gov/airquality/oilandgas/

[128] US Environmental Protection Agency (EPA), 2011, 'Summary of the Requirements for Processes and Equipment at Natural Gas Well Sites', *EPA's Air Rules for the Oil & Natural Gas Industry*. www.epa.gov/airquality/oilandgas/pdfs/20120417summarywellsites.pdf

to the lined flare pit without separation, so that the entrained gas can be combusted safely. Although most of the water-based liquids will drop out and accumulate within the lined flare pit (to be collected later for proper disposal), it is inevitable that some of the chemicals in the flowback liquid will also be combusted.

Todd recently installed shallow piezometer bores in the immediate vicinity of a flare pit, analysing samples for hydrocarbons, chlorides, etc. No contamination was measured.

6.5.2 Use of flare pits

Todd considers the availability of flare pits an essential safety device, enabling gas to be safely combusted during drilling, workover, testing and hydraulic fracturing operations. Lined flare pits provide a controlled environment for the management of well fluids during well control situations, and a safe outlet for highly erosive fluid returns. The latter can occur immediately after fracturing, as the initial fracture return fluids can contain significant amounts of proppant which can be equivalent in effect to sand blasting. This can be highly erosive to the testing facilities, and result in rapid plugging of separation tanks and/or pipework.

At all times Todd endeavours to keep the use of gas flaring to a minimum, to minimise the environmental effects of its activities including noise, and to avoid burning a resource which has the potential to generate revenues. Where Todd has the infrastructure in the vicinity it will be used. At times, however, flaring is required to obtain essential data on the reservoir, and for well, facility and pipeline design. It may, for example, be required to assess reservoir permeability, well/reservoir flow capacity and reservoir connectivity, and to obtain representative reservoir fluid samples for compositional analysis, including for impurities such as hydrogen sulphide, carbon dioxide and mercury. This type of data is typically used for development planning, material selection, equipment design and sizing, etc. The need for flaring typically reduces as the knowledge of a field/reservoir increases and/or nearby infrastructure becomes available as a discovery moves through its lifecycle from exploration to appraisal, development and production.

Todd continually assesses alternative systems and technological developments in this as in all areas of its operations from a sound economic and environmental viewpoint. While Todd originally lined the Mangahewa flare pits with impermeable clay, it is in the process of retrofitting these with plastic liners, notwithstanding the fact that shallow peizometer bores showed no contamination in the vicinity of these pits.

Figure 27 - Flare, flowback fluids [129]

As an example of Todd's current procedures in regard to flaring operations, the following section is an extract from the Health Safety and Environment plan developed for the Waitui-1 and Mangahewa-04 hydraulic fracturing and testing operations. TRC resource consent 7452-1 contains a number of conditions relating to flaring practices and the management of flaring activities during well clean-up and production testing. The resource consent contains conditions relating to:

> Notification of imminent flaring to the Council and all residents within 1,000 metres of the wellsite at least 24 hours prior to the commencement of flaring (the notification must include a 24 hour contact phone number so that neighbours can ring Todd if they have any concerns).

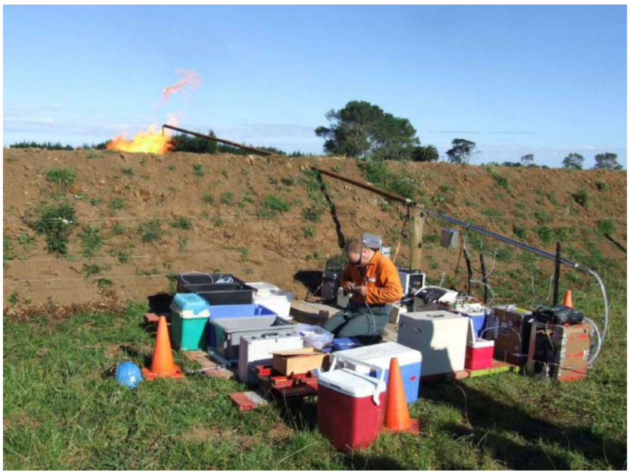
[129] Taranaki Regional Council, May 2012, 'Investigation of air quality arising from flaring of fracturing fluids – emissions and ambient air quality', *TRC Technical Report 2012-03*. http://www.trc.govt.nz/assets/Publications/guidelines-procedures-and-publications/hydraulic-fracturing/Flaring2012-report.pdf

> Keeping a record of all queries and complaints.
> Effectively separating liquids and solids.
> Avoidance of smoke emissions or production of offensive odours (in order to avoid a breach of consent conditions all practicable steps are taken to ensure that smoke emissions are avoided, or failing that minimised).
> Minimising the combustion of liquid or solid hydrocarbons through the flare system (each time there is visible smoke, the time, duration and its cause is recorded).
> Keeping a log of all flaring, including time, duration, zone and volumes of substances flared.
> Monitoring of flare duration to ensure 15 days of flaring per zone is not exceeded.

In 1998, the TRC investigated the nature and dispersion of air emissions and downwind effects arising from the flaring of hydrocarbons (both natural gas and condensate) at wellsites.[130] These studies established that, under combustion conditions of high volume flaring of gases with some light entrained liquids, the atmospheric concentrations of all contaminants had reduced at a distance of 250 metres downwind to a level typical of elsewhere in the Taranaki environment (e.g. in urban areas). It was also revealed that the levels are far below any concentrations at which there is any basis for concern over potential health effects.

More recently, in response to public concern about potential effects arising from the risk of hydraulic fracturing fluids, the TRC undertook a study of the nature of emissions arising from the flaring of fluids recovered from hydraulic fracturing activities and the effects of emissions upon ambient air quality in the vicinity of wellsites.[131] Emissions from the combustion and evaporation zones were analysed for a range of critical parameters (e.g. dioxins, furans, poly-aromatic hydrocarbons (PAHs), aldehydes, VOCs, methanol, particulates) and downwind measurements covered carbon dioxide and dioxide, formaldehyde, VOCs and particulates.

Figure 28 - Combustion zone testing set-up (from TRC report, 2012) [132]



The TRC undertook field measurements at a North Taranaki wellsite during flaring operations, following the hydraulic fracture stimulation and the subsequent flowback. During the flowback period, the full well stream was diverted to the flare pit without separation of the fracture fluids. Measurements were taken at various downwind locations as well as at the flare pit itself.

The study found that, in the case of that particular well operation, "a separation distance of 300 metres between a flare and residential properties gave a substantial health and safety buffer for the protection of local populations". The results were consistent with the 1998 study.[133]

[130] Taranaki Regional Council, August 1998, 'Fletcher Challenge Energy Taranaki Ltd Mangahewa 2 gas well Air Quality Monitoring Programme Report 1997-98'.

[131] Taranaki Regional Council, May 2012, 'Investigation of air quality arising from flaring of fracturing fluids – emissions and ambient air quality', *TRC Technical Report 2012-03*. http://www.trc.govt.nz/assets/Publications/guidelines-procedures-and-publications/hydraulic-fracturing/Flaring2012-report.pdf

[132] Taranaki Regional Council, May 2012, 'Investigation of air quality arising from flaring of fracturing fluids – emissions and ambient air quality', *TRC Technical Report 2012-03*. http://www.trc.govt.nz/assets/Publications/guidelines-procedures-and-publications/hydraulic-fracturing/Flaring2012-report.pdf

[133] Taranaki Regional Council, August 1998, 'Fletcher Challenge Energy Taranaki Ltd Mangahewa 2 gas well Air Quality Monitoring Programme Report 1997-98'.

The TRC concluded that there were minimal effects upon ambient air quality in the vicinity of the flare and that air quality remained high by comparison with guideline values even at 70 metres downwind.

The findings of the study indicate that, at the temperatures encountered in the flares, contaminants associated with hydraulic fracturing fluids are largely destroyed and combustion products are not of a type or concentration that is of concern from a regulatory perspective. This finding is able to be used in the preparation of environmental effects assessments for wellsite consent applications.

6.6 Noise

Excessive noise is potentially an issue for people living near drilling sites, particularly since wellsite operations are often active 24 hours a day, seven days a week. Noise can be generated by traffic coming to and from the drilling site and from the drilling and completion process itself. During hydraulic fracturing operations, the primary sources of noise include:

- engines located on site (power generation, pumps, compressors)
- the rig floor (drawworks, rotary table)
- mixing equipment
- flare pit (during gas flaring operations)
- traffic (cars and trucks coming or going from the site), and
- alarms (infrequent).

During the actual fracturing operation, the main source of noise is from the diesel engines used by the pumping equipment, particularly since the pumps are operating at high flow rates and high pressure. Even though the pumping operations are over within a matter of hours, the noise levels have the potential to exceed allowable limits.

6.6.1 Mitigation of noise effects

With the relatively small scale of fracturing operations in Taranaki, and the number of deliveries of equipment and materials being relatively few, noise from trucks has not been a major issue for the community. Furthermore well pads are generally further than 500 metres away from the nearest homes.

Noise limits for the Todd wellsites set by the New Plymouth District Plan which specifies that maximum allowable noise levels[134] measured at any point within the notional boundary of any receiving site located within the rural environment areas, on any day are:

On any day 7am-10pm	50dBA[135] L_{10}[136]
10pm-7am	45dBA L_{10}
	70dBA L_{max}

For the purpose of applying these noise limits, the notional boundary is considered to be 20 metres from any residential dwelling.

To minimise the noise disturbances resulting from hydraulic fracturing, treatments are pumped only during daylight hours.

[134] Todd Energy, 22 June 2011, 'Mangahewa E Predicted Noise Levels from Well site', *Marshall Day Acoustics.*

[135] dBA is a measurement of sound level which has its frequency characteristics modified by a filter (A-weighted) so as to more closely approximate the frequency bias of the human ear.

[136] L_{10} is the sound level which is equalled or exceeded for 10% of the measurement period. L_{max} is the maximum sound level recorded during the measurement period.

Figure 29 - Temporary noise barrier erected around wellsite equipment

If the operation is unavoidably close to a dwelling and it is not possible to meet these limits it is then necessary to apply for a land use consent to the New Plymouth District Council to temporarily exceed District Plan permitted activity noise limits. It is also necessary to engage with the residents of the affected dwellings with regard to some form of compensation and to obtain their agreement.

At Todd wellsites, noise levels are monitored continuously at various locations using sound level meters to ensure that the regulatory noise limits are not exceeded.

Portable sound barriers are erected around particularly noisy equipment such as the diesel engines. Figure 29 shows an example of a temporary portable sound barrier.

6.7 Seismic activity

On 1 April, 2011, a seismic event was experienced in Blackpool in the United Kingdom with a magnitude of 2.3M.[137] This event occurred shortly after a hydraulic fracture treatment in a shale formation. Another seismic event of magnitude 1.5M occurred on 27 May, 2011 following another hydraulic fracturing operation in the same well. The company involved, Caudrilla, suspended hydraulic fracturing operations and commissioned an investigation into the two events.[138]

The Department of Energy and Climate Change (DECC) also commissioned an independent report into the events. Both reports concluded that the seismic events had been caused by the injection of fluids into a nearby (but previously unidentified) pre-stressed fault, effectively relieving the rock stresses and causing the fault to slip along the fault plane. The resulting seismic response would therefore be very similar to a minor earthquake.

Earthquake magnitude (M) is a measurement of the intensity (the amount of stored energy released) of an earthquake. The table below gives a rough indication of how an earthquake of varying magnitude affects people and objects on the surface close to the epicentre of the earthquake. The largest seismic event recorded during the Blackpool incident, of magnitude 2.3M, would probably not have been felt at surface.

The UK Royal Society and Royal Academy of Engineering noted in their June 2012 report that there is a consensus emerging "that the magnitude of seismicity induced by hydraulic fracturing would be no greater than 3M (felt by few people and resulting in negligible, if any, surface impacts)."[139] Nonetheless, public concerns remain around seismicity and hydraulic fracturing, generally related to shale gas operations in the United Kingdom and North America.

[137] Swint, Brian, 2 November 2011, 'Gas Fracking Probably Caused Earthquakes In U.K.', *Bloomberg.* www.bloomberg.com/news/2011-11-02/gas-fracking-probably-caused-blackpool-earthquakes-in-u-k-.html

[138] Cuadrilla Resources, 2012, 'Hydraulic Fracturing and Seismicity', *Seismicity*. www.cuadrillaresources.com/protecting-our-environment/seismicity/

[139] 'The Royal Society and The Royal Academy of Engineering, June 2012, 'Shale gas extraction in the UK: a review of hydraulic fracturing', *United Kingdom,* p. 4. http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/projects/shale-gas/2012-06-28-Shale-gas.pdf

Table 7- Description of earthquake magnitudes and effects[140]

Magnitude	Description	Earthquake effects
<2.0	Micro	Micro earthquakes, not felt.
2.0–2.9	Minor	Generally not felt, but recorded.
3.0–3.9		Often felt, but rarely causes damage.
4.0–4.9	Light	Noticeable shaking of indoor items, rattling noises. Significant damage unlikely.
5.0–5.9	Moderate	Can cause major damage to poorly constructed buildings over small regions. At most slight damage to well-designed buildings.
6.0–6.9	Strong	Can be destructive in areas up to about 160 km across in populated areas.
7.0–7.9	Major	Can cause serious damage over larger areas.
8.0–8.9	Great	Can cause serious damage in areas several hundred kilometres across.
9.0–9.9		Devastating in areas several thousand kilometres across.
10.0+	Massive	Never recorded, widespread devastation across very large areas.

Public concern in the United States has led to further investigations by government agencies. Fewer than 40 incidents of seismic activity, which were felt at the surface, were potentially associated with the 151,000 Class II injection wells in the United States.[141] Most of the documented cases of seismicity related to fluid injection are associated with water flooding operations for the purpose of secondary recovery of oil, which are not restricted to hydraulic fracturing.[142]

Following New Zealand news media reports on the findings of the Blackpool investigation, concerns were raised that similar events could be triggered in New Zealand. The TRC subsequently commissioned GNS Science to examine the situation in Taranaki and determine whether similar seismic events could be triggered by hydraulic fracturing operations in the region.[143] The GNS Science study detailed seismic events occurring near hydraulic fracturing locations between 2000 and 2011. The GNS assessment included an examination of the likelihood that hydraulic fracturing could have induced seismic events within 10 kilometres of the well, as recorded in the New Zealand earthquake database (GeoNet). There were no cases of recorded seismic events less than three months after hydraulic fracturing operations were undertaken. GNS Science concluded that it was unlikely that any seismicity above magnitude 2M (micro earthquakes) had been triggered by hydraulic fracturing.[144]

6.7.1 Mechanisms for triggering seismicity

The energy applied to the formation during hydraulic fracturing does, by its very nature, involve some extremely localised micro-seismicity. On a geological scale, however, the

[140] Based on US Geological Survey documents. See Earthquakes Today, 2012, 'Richter Scale Table'. http://earthquakestoday.info/

[141] American Petroleum Institute, 2012, 'Injection Wells & Induced Seismicity', *Hydraulic Fracturing*. www.api.org/~/media/Files/Policy/Hydraulic_Fracturing/UIC-amd-Seismicity.ashx

[142] Nicholson, C.; Wesson, R.L., 1990. 'Earthquake Hazard Associated with Deep Well Injection – A Report to the US Environmental Protection Agency', *US Geological Survey Bulletin 1951*. http://foodfreedom.files.wordpress.com/2011/11/earthquake-hazard-associated-with-deep-well-injection-report-to-epa-nicholson-wesson-1990.pdf

[143] Sherburn, Steven, Quinn, Rosemary, February 2012, 'An Assessment of the Effects of Hydraulic Fracturing on Seismicity in the Taranaki Region', GNS Science, *GNS Science Consultancy Report 2012/50*. http://www.trc.govt.nz/assets/Publications/guidelines-procedures-and-publications/hydraulic-fracturing/gns-seismic-feb2012.pdf

[144] *Ibid.*

energy imparted is minor. Given the depth at which conventional fracturing takes place it is highly unlikely that any seismicity would be noticed at the surface. Slightly higher energy events have been linked with fracturing in some countries, but this has generally been related to geothermal projects.

Two types of seismicity can be associated with the injection of high pressure fluids into rock formations. The first type, known as tensile failure, involves opening of new or pre-existing fractures. The second type, referred to as shear failure, involves the parallel sliding of the walls of a fracture. Either kind of failure can cause a micro-seismic response.

Tensile failure

In hydraulic fracturing the aim is to create a controlled tensile fracture propagating out from the borehole. During the process of hydraulic fracturing, sufficient fluid pressure is applied to the rock to cause tensile failure. This is analogous to 'pulling apart' the rock. The required fluid pressure will depend on the tensile strength of the rock exposed to the fracturing fluids. This type of failure induces high frequency signals since the source of the signals is confined to the point of failure. The magnitude of the induced seismicity is very small and unlikely to be felt at the surface.

Shear failure

This is the type of rock failure associated with earthquakes and occurs when pre-stressed rocks fail along a planar surface, such as a fault, causing the adjacent surfaces of the fault plane to move against each other in a 'slipping' movement. If a pre-stressed fault is close to the point of natural failure, it is possible that the introduction of a small amount of additional energy (and the associated forces induced) imparted during the hydraulic fracturing operation may be sufficient to overcome the remaining resistance to failure causing the fault plane to activate. The magnitude of the resultant seismicity depends on the properties of the fault, including: the surface area of the patch of fault plane that has been induced to slip (a larger response is generated by a larger surface area), and the extent to which the fault is pre-stressed (the more stress that is relieved during the event, the greater the response).

6.7.2 Steps to mitigate induced seismicity

Part of the normal risk assessment associated with planning hydraulic fracturing operations includes an assessment of nearby faults. Prudent operators place strong emphasis on identifying the presence of faults from seismic reflection survey data and ensuring the fracturing designs take account of the presence of significant faults to avoid propagating fractures into known faults.

It is not always possible to accurately identify all faults and risks that fluids may be injected into unknown faults remains. However, unknown faults tend to be relatively small which is why they may not be readily identified from seismic reflection surveys. This situation appears to have occurred during the Blackpool incident.

Faults that are small enough to be unidentified in seismic reflection surveys will have a relatively small surface area therefore any seismicity induced during the fracturing operation is unlikely to be felt at the surface. This would be especially true for most Taranaki wells which are typically fractured at depths below three to four kilometres.

The risks of generating seismic activity beyond the fracturing operations planned are negligible.

While the risks of generating seismic activity beyond the fracturing operations planned, including the risk of re-activating old faults, are considered to be negligible, avoiding hydraulic fracturing near faults is good operating practice from the perspective of obtaining a successful fracture treatment result. This is because a fault could act as a 'thief' zone for the fracture treatment, thereby compromising the operational objective, and potentially leading to early programme termination.

In Taranaki, there is no clear evidence of modern day faulting in the formations beneath the Mangahewa wellsites. There are indications that the area was subjected to active faulting during deposition (i.e. faults of Eocene age) more than 30 million years ago, but these faults are no longer active.

The fracturing operations are also closely monitored in real time for the duration of the job. Any concerns or problems are identified and addressed immediately by experts present in the control centre during the operation.[145]

The possibility of undertaking vibration monitoring was reviewed and considered by Todd. The seismic signal resulting from hydraulic fracturing is relatively small. Consequently, the vibration sensors would need to be located reasonably close to the signal to register it. There are two options for vibration monitoring, surface monitoring and downhole micro-seismic monitoring in nearby wells.

Surface monitoring

> The vibration signal is dominated by the surface equipment (five high pressure pumps running at full throttle).

> The small seismic signal resulting from the hydraulic fracturing is generated four kilometres below surface.

> In the Mangahewa field, the Mangahewa Formation contains extensive coal layers in the upper formation above the fracturing zones (coal layers absorb seismic energy resulting in severe signal reduction and poor quality data).

Micro-seismic monitoring

> Micro-seismic monitoring is based on running an array of seismic sensors in a nearby well to register the seismic signals resulting from fracture growth.

> Its feasibility was reviewed for the Kapuni field (jointly owned by Shell and Todd), primarily to assist with reservoir modelling and well spacing decisions.

> The noise level (including surface noise), the vicinity of coals and the rock characteristics determine the maximum feasible distance between the sensors and the area of interest. In the most favourable circumstances this can be up to one kilometre. However, for Kapuni the maximum distance has been modelled as 250 to 400 metres. The Eocene rocks in the Kapuni field are a good analogue for the Eocene rocks in the Mangahewa field and both contain coal layers.

> Currently, well spacing in the Mangahewa field is far too coarse for micro-seismic monitoring (i.e. no wells within 1,500 metres of each other) to obtain any useful data.

> Based on the assessment above, Todd concluded that vibration monitoring is currently not suitable for the Mangahewa wells.

[145] In particular, annulus pressure (the annulus between the tubing, which is the pipe string used for fluid injection, and the surface casing) is closely monitored throughout the pumping operation. Any sudden change in pressure would signify a loss of well integrity at which point the pumping operation would immediately cease. This virtually eliminates the risk of injecting treatment fluids into shallow freshwater aquifers.

6.7.3 Case study: Canadian investigation into seismicity

Between April 2009 and December 2011 the British Columbia Oil and Gas Commission (Commission) investigated anomalous seismicity within remote areas of the Horn River Basin.[146]

The Commission consulted with several organisations, including Natural Resources Canada (NRCan), and Alberta Geological Survey and the University of British Columbia. Data for the investigation was gathered from a number of sources including open source information as well as data received by oil and gas companies working in the vicinity of the investigation.

The Commission noted that more than 8,000 high-volume hydraulic fracturing completions were performed in northeast British Columbia with no associated anomalous seismicity.

Three sets of events are discussed in the report; the 38 events reported by NRCan, 216 events recorded by a dense array deployed at Etsho and 18 events recorded by a dense array deployed at Kiwigana. All of these events were interpreted to be the result of natural fault movement.

Wells used for fluid disposal were ruled out as a source of the seismicity during the investigation. There were four disposal wells operating during the period of observed seismicity; three at Etsho and one in the Tattoo area. All of these wells were injecting recovered hydraulic fracturing fluids into the Mississippian Debolt Formation, which is 1,800 metres above the Horn River Group. All event epicentres occurred within the Devonian Horn River Group and no fault movement was seen in the Debolt Formation.[147]

6.8 Emerging technology

Public concern over possible contamination of groundwater aquifers has arisen mainly in the United States and relates primarily to shale gas and coal seam gas hydraulic fracturing developments. As noted earlier, these operations typically involve fracture treatments at shallower depths, and the volumes of fluid used (with associated chemical additives) are much larger than are applied in hydraulic fracturing operations in deep, low permeability sandstone reservoirs. Oilfield service companies have been responding to these concerns in a number of ways, including the development of environmentally friendlier chemicals for use in fracturing fluids.

6.8.1 "Green" fracturing fluids

Halliburton has been promoting the use of its proprietary *CleanStim* formulation which it states is made up of ingredients sourced from the food industry.[148] The basic requirements for the fluid still exist including a gelling agent, a crosslinker/buffer, gel breakers and a surfactant. The system is still undergoing field trials in the United States at bottomhole temperatures of up to 225 degrees Fahrenheit. Application to relatively deep wells may be limited due to higher temperatures experienced (note: bottom-hole temperatures in the Mangahewa field are up to 300 degrees Fahrenheit). The *CleanStim* fluids are part of Halliburton's *CleanSuite* technologies[149] which also includes the

[146] BC Oil & Gas Commission, August 2012, 'Investigation of Observed Seismicity in the Horn River Basin.' http://www.bcogc.ca/document.aspx?documentID=1270

[147] *Ibid*, p. 4.

[148] Halliburton, 2012, 'CleanStim Hydraulic Fracturing Fluid System', *Fracturing*. www.halliburton.com/ps/default.aspx?pageid=4184&navid=93&AdType=JPTCSTC

[149] Halliburton, 2012, 'CleanSuite Technologies', *Hydraulic Fracturing*. www.halliburton.com/public/projects/pubsdata/hydraulic_fracturing/CleanSuite_Technologies.html

CleanStream service,[150] an alternative to using bactericides in the fracturing fluid. *CleanStream* employs ultraviolet light to kill bacteria as the treating fluid is being pumped replacing the need for chemical bactericides.

Baker Hughes has developed its own more environmentally benign fracturing fluids known as the *SmartCare* system of products and services.[151] These are designed to achieve the same results as conventional fracturing fluids, using ingredients that are either benign or break down readily to become so after use.

Chesapeake is testing hydraulic fracturing fluids made entirely of environmentally-benign components.

Chesapeake Energy Corp, the second largest natural gas producer in the United States, recently announced that it is testing hydraulic fracturing fluids made entirely of environmentally-benign components.[152]

In addition to replacing various chemicals with "green" chemicals, service companies are also attempting to minimise the overall volume of chemicals required for making up fracturing fluids.

6.8.2 Gelled LPG fracturing

A relatively new technology is currently under development in the United States by Gasfrac Energy Services, a small Canadian company. It employs a gelled propane[153] to replace water as the base carrier fluid for use in shale gas fracturing operations. The primary goal is to reduce the requirement for large volumes of water.[154] A further benefit is that there is no water from the fracturing fluid left in the reservoir. This should result in improved well performance post-treatment. The use of gelled propane does, however, have significant safety implications.

Given the relatively low volumes of water used in Taranaki applications, and the plentiful supply of freshwater in the region, the issue of water use is much less of a concern than in shale gas development in the United States, where much larger volumes of water are required, often in areas of limited supply, and in areas of potential shale gas development in the United Kingdom, where the population density is generally much higher.

6.8.3 Gaseous fracturing fluids

Lightweight proppants have been developed for use with nitrogen or carbon dioxide injection as a fracturing fluid for use in water sensitive, low pressure reservoirs. Baker Hughes has developed a system marketed as *VaporFrac*.[155] This system would not be applicable to Taranaki where the gas reservoirs are relatively highly pressured.

6.8.4 Horizontal, multistage fracture treatments

Shale gas developments have been made possible through the application of long, horizontal completions sometimes using multi-lateral designs, where multiple horizontal wellbores within the reservoir sharing a common wellbore to the surface. This application

[150] Halliburton, 2012, 'CleanStream Ultraviolet Light Bacteria Control Process', *Water-based Gel Systems*. www.halliburton.com/ps/Default.aspx?navid=105&pageid=4760&prodid=PRN%3a%3aKO6K5215&TOPIC=HydraulicFracturing

[151] Baker Hughes, 2012, 'Reduce environmental risk using optimal stimulation solutions', *SmartCare Products and Services*. www.bakerhughes.com/products-and-services/pressure-pumping/hydraulic-fracturing/smartcare-products-and-services

[152] Carroll, Joe, 2 October 2012, 'Chesapeake Testing 'Green' Fracking Fluids in Shale Wells', *Bloomberg Businessweek*. http://www.businessweek.com/news/2012-10-02/chesapeake-testing-green-fracking-fluids-in-u-dot-s-dot-shale-wells

[153] Royal Society of Chemistry, 15 November 2011, 'Fracking with Propane Gel', *Chemistry World*. www.rsc.org/chemistryworld/News/2011/November/15111102.asp

[154] Harrington, Kent, 29 May 2012, 'GASFRAC Takes the Water out of Fracking', Chenected, http://chenected.aiche.org/energy/gasfrac-takes-the-water-out-of-fracking/

[155] Baker Hughes, 2012, 'Improve production in water-sensitive, low-pressure reservoirs', *VaporFrac Fracturing Fluid.* www.bakerhughes.com/products-and-services/pressure-pumping/hydraulic-fracturing/vaporfrac-fracturing-fluid

is combined with staged, hydraulic fracture treatments. The same technology can be used in tight sandstone reservoirs which have the potential to greatly reduce the number of wells required to effectively develop a gas field.

A common type of well completion in horizontal wells involves the use of swell packers to divide the horizontal sections into segments.[156] These segments can then be individually stimulated by means of sequential hydraulic fracture treatments. Swell packers use elastomers which swell slowly (to avoid premature setting) when in contact with wellbore fluids and provide an alternative to mechanical packers or cement isolation. New completion systems incorporate multiple sleeves which can be sequentially opened by pumping balls down the well. They actuate the sleeves, allowing hydraulic access to the formation to be stimulated. Halliburton's new *RapidFrac* system is an example of this new technology.[157]

Hydraulic fracturing sleeves which can be opened and closed by coiled tubing are also being marketed.

Todd is currently evaluating the possible application of this technology for the Mangahewa field. The conceptual design involves a single, sub-horizontal well (inclined to intersect multiple gas sands). This would be completed within the reservoir section using swell packers to compartmentalise individual zones, combined with the use of multiple hydraulic fracturing sleeves.

Conclusion

The primary environmental concern raised in relation to hydraulic fracturing is the risk of contaminating shallow freshwater aquifers and surface water with hydrocarbons or fracture fluids.

Todd uses state-of-the-art well construction, testing and monitoring procedures. Wells are designed, constructed and abandoned in line with industry best practice standards and New Zealand regulations. Operations are likewise designed, conducted and monitored at the highest standards. The risk of fractures extending into aquifers or fluids escaping up between the well and surrounding rock, particularly at the depths involved, is virtually non-existent.

The types of chemicals used for hydraulic fracturing have changed substantially over the last twenty years. Most are environmentally benign and are common in many household products. Fracturing fluids that are 100 percent benign are rapidly coming on market. Fracture fluid composition is fully disclosed in consents and on many company websites.

Todd places a strong emphasis on minimising air, noise and visual pollution by consulting with local communities regularly, taking additional safety and environmental precautions and using processes such as flaring only when absolutely necessary.

By its nature hydraulic fracturing does induce micro-seismic activity, but on a geological scale this is minor (below 2M) and not felt at the surface. Identification and avoidance of any existing nearby faults is part of normal risk assessment and the risk of re-activating old faults is considered negligible.

A study undertaken by GNS Science concluded it was unlikely that any seismic event above magnitude 2M (micro earthquakes) has been triggered by hydraulic fracturing in New Zealand.

Many of the environmental risks raised as concerns relating to hydraulic fracturing apply to all exploration and production drilling. They are well recognised by the industry and managed through adherence to high quality well construction and best practice in all aspects of the operations.

[156] Halliburton, 2012, 'Swell Technology™ Systems', *Products & Services*. www.halliburton.com/ps/default.aspx?pageid=79&navid=153

[157] World Oil Online, 15 August 2011, 'Halliburton introduces RapidFrac completion system', *World Oil News Centre*. www.worldoil.com/Halliburton_introduces_RapidFrac_completion_system.html

CHAPTER 7

Economic, Social and Environmental Benefits

This chapter outlines some of the benefits related to hydraulic fracturing:

> Economic benefits
> Case study – Mangahewa development
> Social benefits
> Environmental benefits

7.1 Economic benefits[158]

The oil and gas sector plays a significant role in the New Zealand economy. In addition to supplying approximately 19 percent of the country's total primary energy requirements from indigenous reserves,[159] it employs thousands of New Zealanders, contributes hundreds of millions of dollars in revenue to the government and helps grow New Zealand businesses.

Hydraulic fracturing is an increasingly important tool for the oil and gas sector. It enables more oil and gas to be retrieved from existing fields than was previously thought possible, and is bringing new fields online that would otherwise be uneconomic. It is an important way to sustain the benefits the industry confers on New Zealand, especially as traditional, large fields like Maui approach the end of their productive lives.

7.1.1 GDP and employment

The oil and gas sector contributes approximately $1.8 billion to GDP per year, rising to $2.2 billion once flow-on effects are included.[160] This is equal to over one percent of GDP.[161]

The relative economic importance of the oil and gas sector is greatest in Taranaki, where the vast majority of its activity is based. The sector directly contributes approximately $1.7 billion annually to regional GDP, rising to $1.85 billion with flow-on effects. This makes it responsible for approximately 32 percent of regional GDP. By comparison, Taranaki's other major industry, dairy, directly contributes $680 million.[162]

The sector employs thousands of New Zealanders and helps grow NZ businesses.

Nationally the sector employs approximately 3,400 full-time equivalent (FTE) staff directly, rising to 6,000 once flow-on effects are taken into account. In Taranaki the figures are 3,200 and 4,200 FTE jobs respectively. The direct Taranaki jobs are particularly valuable, given their high average labour productivity of $525,000 per FTE worker. This compares with labour productivity for dairy at $105,000 per worker, and a regional average of just $103,000.[163]

Over the five years to 2011, the New Plymouth had the fastest growth of all New Zealand cities in employment, GDP and business units, largely due to the oil and gas sector.[164] The region is currently experiencing a shortage of skilled labour and is actively advertising to attract workers.

Hydraulic fracturing is directly responsible for sustaining these GDP and job benefits. For example, it was pivotal to the $760 million development of the Mangahewa field, which would not have been developed without the technology.[165]

[158] Note: this section uses the latest publically available statistics at the time of publication. Unfortunately some statistics are two or more years old. Todd is contributing data to a Venture Taranaki research project that aims to provide a more up to date snapshot of the contribution the oil and gas sector makes to the economy. We look forward to seeing the results of this work.

[159] Ministry of Economic Development (NZ), 2012, 'Energy Data File', *Table A.2: Total Primary Energy Supply*, p. 10. http://www.med.govt.nz/sectors-industries/energy/pdf-docs-library/energy-data-and-modelling/publications/energy-data-file/energydatafile-2011.pdf

[160] Leung-Wai, Jason (BERL Economics), Stone, Chris, Campbell, Ross (Rockpoint), October 2010, 'The Oil and Gas Industry in New Zealand and Taranaki 2010', *A description and economic impact*, p. 33.

[161] Statistics New Zealand, 20 September 2012, 'Gross Domestic Product: June 2012 quarter', *Key Facts.* http://www.stats.govt.nz/browse_for_stats/economic_indicators/GDP/GrossDomesticProduct_HOTPJun12qtr.aspx

[162] Leung-Wai, Jason (BERL Economics), Stone, Chris, Campbell, Ross (Rockpoint), October 2010, 'The Oil and Gas Industry in New Zealand and Taranaki 2010', *A description and economic impact*, p. 34.

[163] *Ibid*, pp. 33-34.

[164] Leung-Wai, Jason, Dustow, Kelly, Molano, Wilma (BERL Economics), March 2012, 'BERL Regional Rankings 2011', *BERL Economics #5214*, p 34. http://www.berl.co.nz/assets/Economic-Insights/Economic-Development/Regions/BERL-Regional-Rankings-Report-2011.pdf

[165] Leung-Wai, Jason, Dixon, Hugh (BERL Economics), January 2012, 'Economic Impact of Oil and Gas Investment in Taranaki and Nationally', (Report to Todd Energy), *BERL Economics*, p. 4.

The economic consultancy Business Economics Research Limited (BERL) has estimated that the sector's contribution to Taranaki's economy could grow to $4.8 billion by 2026 if exploration is allowed to continue.[166]

7.1.2 Royalties and taxes

The oil and gas sector pays significant royalties to the government each year. For the five years from 2008/9 to 2012/13 Treasury expects to receive a total of $2.1 billion, including $375 million for the 2012/13 year.[167] $375 million is equivalent to over 80 percent of the government's conservation budget.[168]

Petroleum royalties are typically based on the greater of five percent of the value of sales from a petroleum field, or 20 percent of field profits. For most producing fields the latter method is used.[169]

In addition to royalty payments oil and gas firms pay business, goods and services and other taxes and rates. For example, the Ministry of Economic Development (MED) estimated that in total the government received approximately $1 billion in taxes and royalty payments from the oil and gas sector in the 2009/10 year (the latest year for which it has published an estimate).[170] This amounts to more than half the police budget or over a third of the tertiary education budget.[171]

Replacing the revenue stream the government receives from the oil and gas sector is likely to necessitate more government borrowing. Tax rate rises would need to be significant to replace the sector's contribution. For example, one percentage point increases in the top personal and company tax rates would net only around $185 million and $290 million respectively.[172]

MED has estimated the net present value of future royalty payments from existing oil and gas fields at $3.2 billion, as shown in Figure 30 below.[173] The Ministry of Business, Innovation and Employment has projected that ongoing exploration could lead to new producing fields and royalty revenue with a net present value between $5.3 billion and

[166] Business and Economics Research Limited (BERL), November 2007, 'Taranaki Industry Projections 2006-2026', *Report to Venture Taranaki*, (Table 5.2: Forecast GDP growth in Taranaki), p. 51. http://www.taranaki.info/admin/data/business/taranaki_industry_projections_2007.pdf

Inflation adjusted to 2012 dollars using: Reserve Bank of New Zealand, 2012, 'New Zealand Inflation Calculator', *Statistics*, using 2006 fourth quarter and 2012 second quarter General Consumer Price Index data. http://www.rbnz.govt.nz/statistics/0135595.html

[167] 2008/9: $543 million, 2009/10: $432 million, 2010/11: $385 million, 2011/12: $335 million (figures include petroleum royalties and the Energy Resources Levy (for natural gas)).
The Treasury, 24 May 2004, 'Budget 2012', *Revenue Data – Estimates of Appropriations 2012/13 tables, Raw data table*. http://www.treasury.govt.nz/budget/2012/data

[168] The Treasury, 24 May 2004, 'Budget 2012', *Estimates of Appropriations for the Government of New Zealand for the Year Ending 30 June 2013*, p. xxviii. http://www.parliament.nz/NR/rdonlyres/690462FC-0436-4B5C-8319-2EE07A5CFC7B/222547/DBHOH_PAP_22909_Budget2012EstimatesofAppropriation.pdf

Note: these figures include petroleum royalties and gas energy resource levies.

[169] Ministry of Economic Development (NZ), January 2012, 'Revised Minerals Programme for Petroleum', p. 81. http://www.nzpam.govt.nz/cms/pdf-library/petroleum-legislation-1/Minerals%20Programme%20for%20Petroleum%20-2005-%20Amendement%20-PIT%20Removal-%202012.pdf

Note: for petroleum licences granted before 1995 legacy royalty rates apply and for gas discoveries made before 1 January 1986 an Energy Resources Levy (ERL) of $0.45 per GJ of gas produced must be paid.

[170] Ministry of Economic Development (NZ), March 2012, 'Review of the Royalty Regime for Petroleum', *Background to the regime and options for changes*, p. 15. http://www.med.govt.nz/sectors-industries/natural-resources/pdf-docs-library/oil-and-gas/crown-minerals-act-review/review-of-the-royalty-regime-for-petroleum.pdf

Note: the Ministry of Economic Development has now been incorporated into the Ministry of Business, Innovation and Employment.

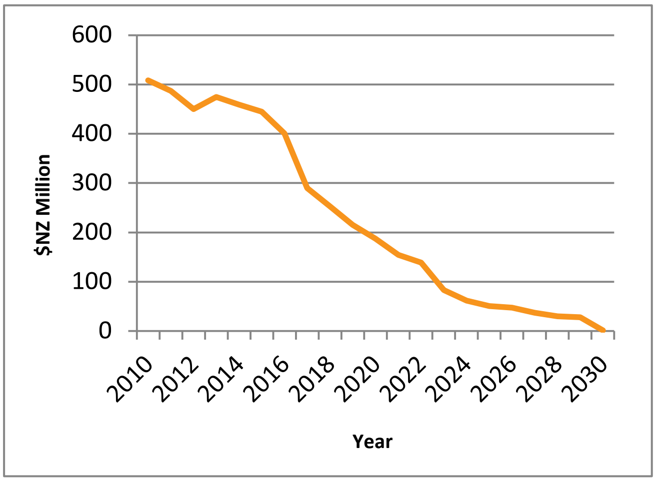
[171] The Treasury, 24 May 2004, 'Budget 2012', *Estimates of Appropriations for the Government of New Zealand for the Year Ending 30 June 2013*, *Summary Tables: Total Appropriations for Each Vote*, p. xxix. http://www.parliament.nz/NR/rdonlyres/690462FC-0436-4B5C-8319-2EE07A5CFC7B/222547/DBHOH_PAP_22909_Budget2012EstimatesofAppropriation.pdf

[172] The Treasury (NZ), 24 May 2012, 'Revenue Effect of Changes to Key Tax Rates, Bases and Thresholds for 2012/13', *Revenue*. http://www.treasury.govt.nz/government/revenue/estimatesrevenueeffects/estimates

[173] Ministry of Economic Development (NZ), March 2012, 'Review of the Royalty Regime for Petroleum', *Background to the regime and options for changes*, p. 15. http://www.med.govt.nz/sectors-industries/natural-resources/pdf-docs-library/oil-and-gas/crown-minerals-act-review/review-of-the-royalty-regime-for-petroleum.pdf

$9.5 billion.[174] Company and income taxes and rates would be paid in addition to these figures, as would receipts from any coal seam gas and shale gas developments.

Figure 30 - Forecast annual royalties from currently-producing fields[175]



Hydraulic fracturing is essential to maintaining and developing these revenue streams for the government. Without hydraulic fracturing, many existing fields, such as Mangahewa and Kapuni, would either not have entered commercial production, or would already have ceased commercial production.[176] The technology will likely become increasingly important as output from large traditional fields like Maui continues to decrease.

7.1.3 Uses of natural gas in New Zealand

Natural gas provided 159 PJ, or 19 percent, of New Zealand's total primary energy supply of 818 PJ in 2011.[177] As such it plays a very important role in New Zealand's energy mix.

All natural gas extracted in New Zealand is consumed or processed domestically. It provides the fuel for electricity generation, home gas connections, and is the feedstock for the production of LPG, methanol, and fertiliser.

Almost all oil produced in New Zealand is exported. This is because it is a high quality oil (sweet, light crude), and is not suitable for refining at New Zealand's only oil refinery at Marsden Point.

Electricity generation

In 2011, natural gas provided 18 percent of New Zealand's electricity supply.[178] It is the second most important source of electricity after hydro.[179]

The value of natural gas in electricity production is further enhanced by the fact it provides backup generation capacity, both at short notice and in dry years when hydro generation falls below average. Natural gas is not weather or lake level dependent and can be fed into the electricity network quickly when needed via peaker power stations. It ensures consistent, reliable supply year round, and minimises the price spikes that would otherwise be necessary to control demand.

Todd is currently commissioning a 100 megawatt (MW) gas fired power station at its McKee oil and gas production station. It also owns, or has substantial interests in, several

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[174] Ministry of Business Innovation and Employment (NZ), August 2012, 'Economic contribution and potential of New Zealand's oil and gas industry', *Economic Development Group Occasional Paper 12/07*, p. 19. http://www.med.govt.nz/about-us/publications/publications-by-topic/occasional-papers/2012-occasional-papers/12-07.pdf

[175] Note: this graphic shows nominal royalty payments to the Crown. The Ministry of Economic Development used a ten percent discount rate to arrive at the $3.2 billion figure, from their nominal estimate of $4.4 billion

[176] Hydraulic fracturing has also enabled or enhanced ongoing operations at these Taranaki fields: Turangi, Kowhai, W.aitui, Kaimiro, Ngatoro, Radnor, Cardiff, Cheal, Rimu, Kauri and Manutahi.

[177] Ministry of Economic Development (NZ), 2012, 'Energy Data File', *Table A.2: Total Primary Energy Supply*, p. 10. http://www.med.govt.nz/sectors-industries/energy/pdf-docs-library/energy-data-and-modelling/publications/energy-data-file/energydatafile-2011.pdf

[178] Ministry of Economic Development (NZ), 2012, 'Energy Data File', *Table G.2b: Net Electricity Generation by Fuel Type*, p. 109. http://www.med.govt.nz/sectors-industries/energy/pdf-docs-library/energy-data-and-modelling/publications/energy-data-file/energydatafile-2011.pdf

[179] *Ibid*, 'Table G.2a: Net Electricity Generation by Fuel Type', p. 108.

smaller stations at Kapuni, Mangahewa and McKee, and at Fonterra's dairy factories in Whareroa and Edgecumbe.

Onsite co-generation

Natural gas is an efficient means of meeting the needs of major energy users. These are users who consume so much energy that it is more efficient to build electricity generation capacity on site, than to supply them from the national grid. The efficiency gains stem from avoiding the energy losses involved in transporting electricity through the grid.

Two examples of onsite generation are Fonterra's Whareroa and Edgecumbe dairy factories, both of which Todd supplies with electricity and steam via onsite natural gas fired co-generation plants.

Case study: Whareroa dairy factory

This is the largest single site dairy factory in the world. It requires a million tonnes of steam per year, as well as enough electricity to power a city the size of Napier. Todd supplies the factory with five PJ of natural gas per year from the Kapuni field via a 22 kilometre dedicated gas pipeline. The natural gas is converted to steam and electricity onsite using a highly efficient 70 MW co-generation plant.

The plant's four gas turbine engines burn natural gas to power generators to produce electricity. Exhaust heat from the turbines is captured and channelled through heat exchangers to produce enough steam to meet the needs of the factory. In the off-season, when steam demand is lower, the surplus is diverted to a steam turbine to generate further electricity, reducing the amount of gas consumed. This form of power generation results in considerable energy savings.

Commercial and retail gas

There are approximately 247,000 residential and 10,000 commercial reticulated natural gas users in New Zealand.[180] Together they account for approximately seven percent of total natural gas consumption.[181] In the North Island natural gas is transported from production facilities in Taranaki to homes and businesses via the 3,500 kilometre high pressure gas pipeline network.[182] This is shown in Figure 31. Those not connected to the network, including all of the South Island, can access natural gas in the form of LPG. There are LPG reticulation facilities in Christchurch and Queenstown. New Zealand consumed seven PJ of LPG in 2011.[183]

Natural gas is an efficient means of meeting the needs of major energy users.

In order to ensure a continuing domestic supply of LPG, Todd opened a new $75 million LPG extraction plant near Waitara in 2011. The plant takes gas from the Mangahewa and Pohokura fields and has a production capacity of 27,000 tonnes per year.

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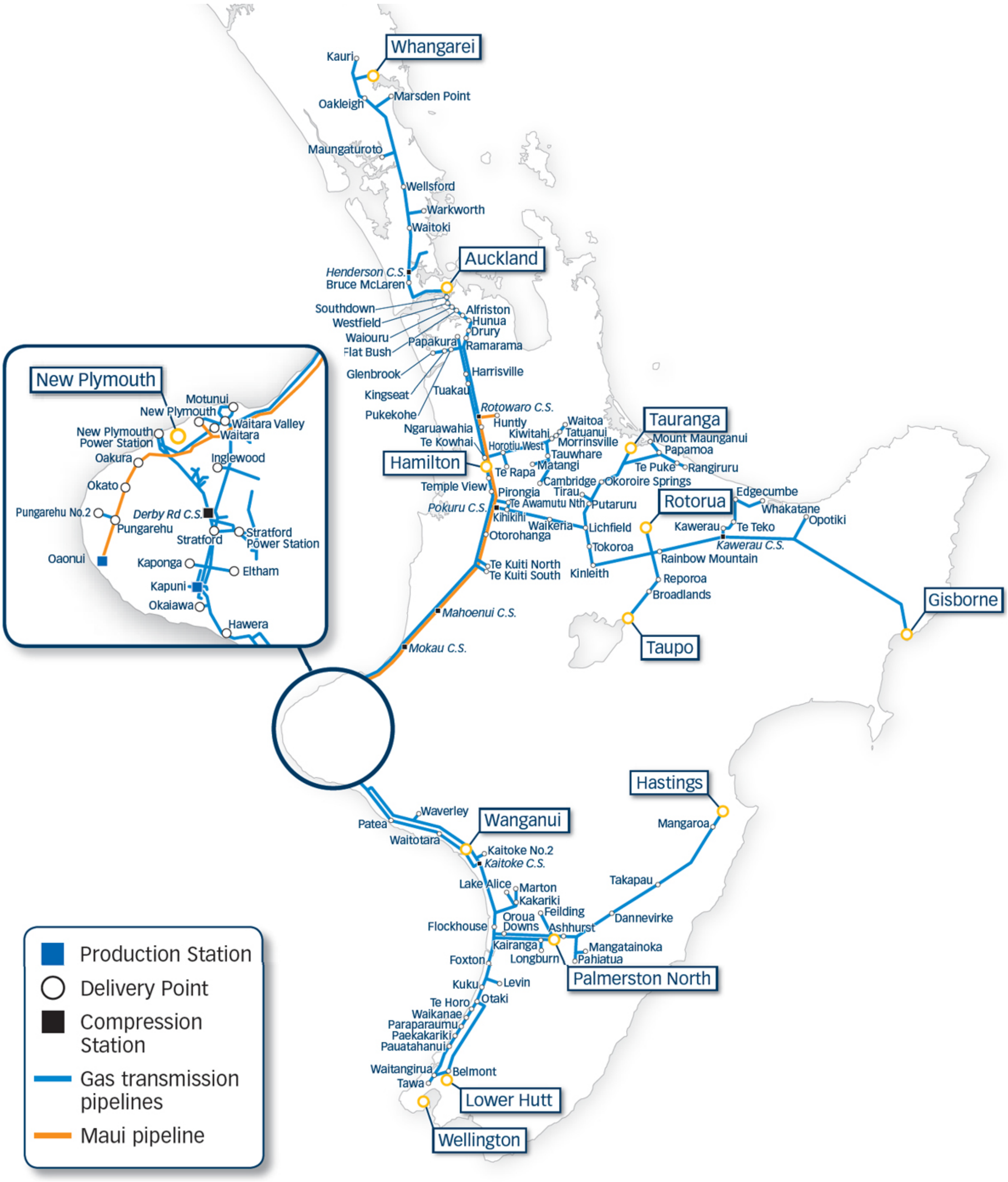
[180] Ministry of Economic Development (NZ), 2012, 'Energy Data File', p. 75. http://www.med.govt.nz/sectors-industries/energy/pdf-docs-library/energy-data-and-modelling/publications/energy-data-file/energydatafile-2011.pdf

[181] *Ibid*.

[182] *Ibid*, p. 74.

[183] *Ibid*, p. 63.

Figure 31 – Transmission pipeline map[184]



Use as petrochemical feedstock

Natural gas has many uses beyond domestic heating and cooking, electricity and steam generation and LPG production. In New Zealand, natural gas is the feedstock for methanol, ammonia, urea and peroxide production by Methanex, Ballance Agri-Nutrients and Degussa, respectively. Methanol fulfils many roles in modern life, some of which are

[184] http://vector.co.nz/sites/vector.co.nz/files/Transmission%20pipeline%20map.pdf

shown in Figure 32. Fertiliser made by Balance Agri-Nutrients is an important input into the primary sector and provides some protection against price fluctuations in global commodity markets and currencies. Feedstock uses represented approximately 25 PJ, or 16 percent of natural gas consumption in 2011.[185]

Figure 32 – the many uses of methanol in our everyday lives

Primary Derivatives	Derivatives	Diverse Demand Drivers
FORMALDEHYDE	Urea formaldehyde Phenol formaldehyde 1,4-butanediol Acetal Resins	Renovation, new building activity, automobile production, panelboard substitution for solid wood, changing wood panel mix, growth in high technology chemicals.
ACETIC ACID	Vinyl acetate monomer Acetic anhydride Terephthalic acid Solvent acetate Solvent esters	Building activity, durables output, automobile production, clean air legislation, packaging trends, growth in plastic recycling, paints and coatings.
CLEAN FUELS	Methanol/water blends - fuel cell "hydrogen-carrier" Reformulated gasoline - MTBE	Demand for better health/cleaner environment, clean air legislative goals, displacement of gasoline components (e.g. lead, aromatics), safety and engine performance.
OTHER	Methyl methacrylate Methylamines Chloromethanes Direct use	Total chemical production, general economic activity, alternative fuel developments, environmental pressures.

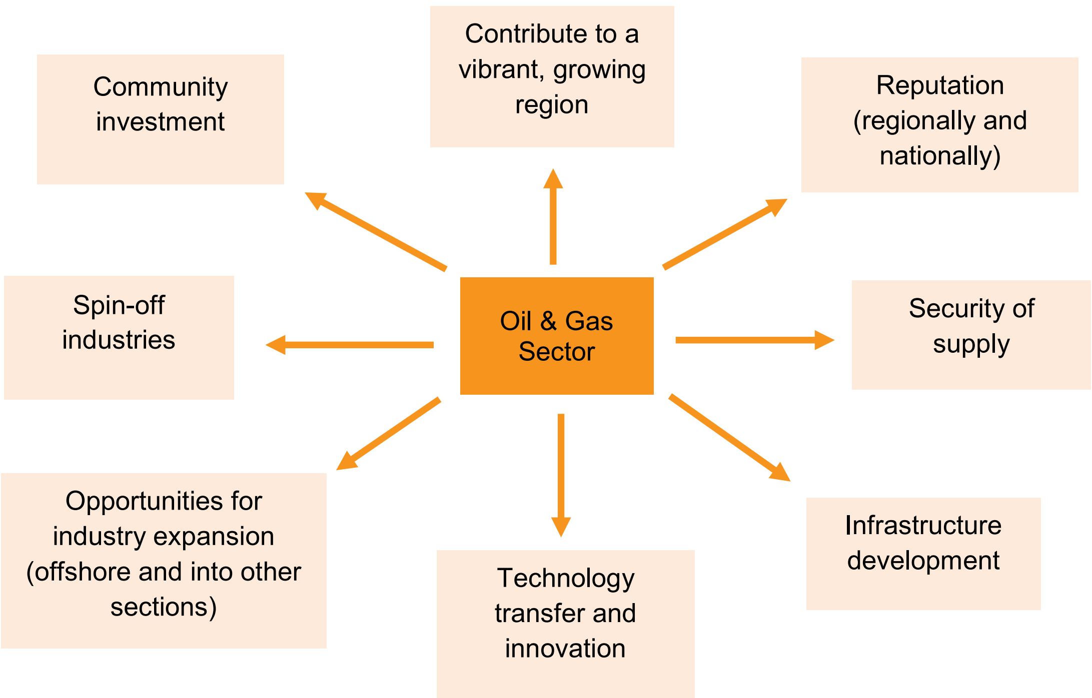
[185] Ministry of Economic Development (NZ), 2012, 'Energy Data File', p. 74. http://www.med.govt.nz/sectors-industries/energy/pdf-docs-library/energy-data-and-modelling/publications/energy-data-file/energydatafile-2011.pdf

Methanex and Ballance Agri-Nutrients together directly contribute about $120 million to GDP, rising to $300 million once flow-on effects are taken into account. They are directly responsible for 360 FTE jobs and 1,710 FTE jobs once flow-on effects are factored in.[186] These numbers are expected to increase in 2012 and beyond, as Methanex restarts the second methanol manufacturing plant at its Motunui facility north of New Plymouth. This has been made possible by the success of Todd's hydraulic fracturing operations at its Mangahewa field, which enabled it to sign a 10 year natural gas supply agreement with Methanex.

7.1.4 Wider intangible economic benefits

The oil and gas industry provides intangible economic benefits to Taranaki associated with having a highly technical, capital intensive industry operating in the region. Figure 33 summarises these benefits.

Figure 33 – Wider economic benefits of the oil and gas industry



The industry provides entry-level training opportunities for people wishing to join the oil and gas sector. It established the Petroleum Skills Association in order to promote opportunities in the industry and to match demand for labour with supply. Training in any of the many skills required by the sector provides New Zealanders with the opportunity to secure a high-earning career in New Zealand or to work overseas if they choose. Many of those who leave return in due course to re-join the New Zealand energy sector.

The capabilities and skills gained in the oil and gas sector are also being applied to spin-off industries. For example, Todd uses its energy experience to run its geothermal plant at Kawerau. Fitzroy Engineering's experience supplying the sector has led to the establishment of Fitzroy Yachts, a major player in the New Zealand super yacht industry. The high wages paid by oil and gas companies, such as Todd, in Taranaki also provide the critical mass to sustain a local retail and restaurant scene that is more vibrant than might otherwise be the case.[187]

[186] Leung-Wai, Jason (BERL Economics), Stone, Chris, Campbell, Ross (Rockpoint), October 2010, 'The Oil and Gas Industry in New Zealand and Taranaki 2010', *A description and economic impact*, p. 43.

[187] Venture Taranaki, December 2010, 'The Wealth Beneath Our Feet', *The Value of the Oil and Gas Industry to New Zealand and the Taranaki Region*: *A fresh perspective on the industry and its economic impact*, p. 43. http://www.taranaki.info/news/files/211.pdf

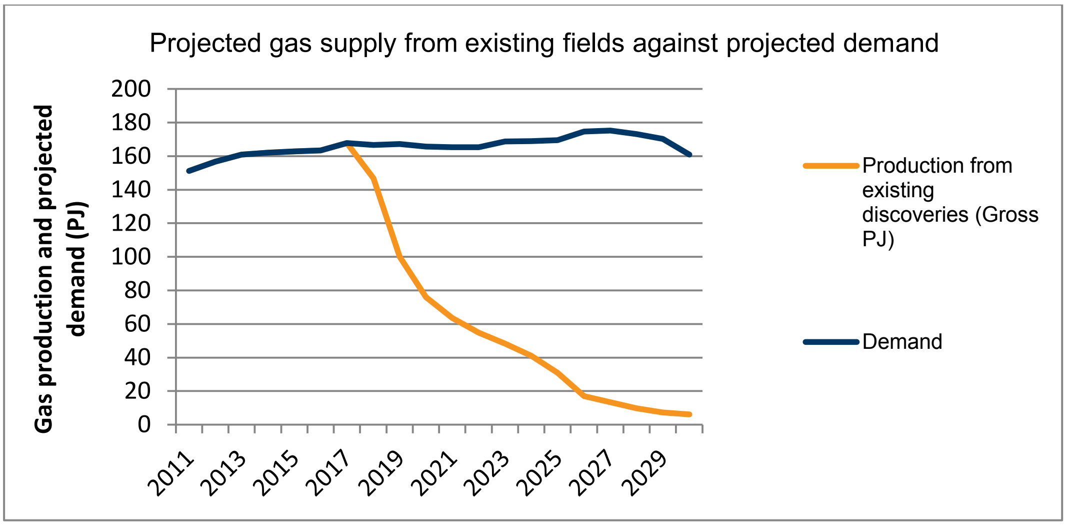
7.1.5 Long-term security of natural gas supply

The oil and gas sector in New Zealand was for a long time dominated by large fields, notably Maui and Kapuni, which the "think big" projects of the Muldoon-era sought to utilise. As production from these and other fields starts to wind down, see Table 8, it is becoming increasingly important to find and access new reserves.[188] As Figure 34 shows, demand for natural gas will outstrip supply from about 2017 onwards at current prices. Hydraulic fracturing is an essential tool for maximising the country's oil and gas resources and has enabled or enhanced on-going operations at ten fields in Taranaki: Turangi, Mangahewa, Kowhai, Kaimiro, Ngatoro, Cheal, Kapuni, Rimu, Kauri and Manutahi.

Table 8 – Oil and gas reserves (expectation case (P50)) – PJ

Field	Ultimately Recoverable Gas PJ	Gas Reserves Remaining PJ	% of NZ gas reserves on 1/1/2012
Pohokura	1222.5	860.3	43
Kupe	286.6	248.2	12
Maui	4103.0	207.9	10
Turangi	247.6	200.9	10
Mangahewa	245.9	180.5	9
Kapuni	1089.0	143.1	7
Kohwai	73.7	56.6	3
McKee	198.5	52.1	3
Others	231.6	49.2	2
Total	**7698.3**	**1998.8**	**100**

Figure 34 – New Zealand gas production and known reserves



[188] See Ministry of Economic Development (NZ), 2012, 'Energy Data File', *Table E.2c: Total Natural Gas Production by Field*, p. 80, and *Table H.2: Oil and Condensate Reserves*, p. 130 and *Table H.3: Gas Reserves*, p. 131. http://www.med.govt.nz/sectors-industries/energy/pdf-docs-library/energy-data-and-modelling/publications/energy-data-file/energydatafile-2011.pdf

7.2 Case study: Mangahewa development

Todd's Mangahewa development gives an insight into how hydraulic fracturing can sustain natural gas supplies and lock in the economic and social benefits associated with the oil and gas industry for many years to come.

The Mangahewa development is analysed under four headings – capital expenditure, operating expenditure, royalties and additional benefits. The capital and operating expenditure distinction reflects the difference between benefits related to establishing the project, and those related to running it once established. Developing the Mangahewa field is expected to take seven years and produce oil and gas for 23 years.[189]

7.2.1 Capital expenditure

Todd will invest in excess of $760 million over seven years in developing the Mangahewa field. It is estimated that at least $390 million of this expenditure will be in New Zealand, with the majority to be spent in Taranaki.[190]

This investment translates to a direct boost to Taranaki's GDP of approximately $180 million and the creation of up to 390 FTE jobs. Once flow-on effects are factored in, GDP is expected to benefit by $270 million and 1,060 FTE jobs will be created.[191]

On a national scale Todd's capital investment in the Mangahewa field translates into a direct boost of $250 million to GDP and up to 450 FTE jobs. With flow-on effects this equates to a $400 million boost to GDP and 1,360 FTE jobs.[192]

7.2.2 Operating expenditure

The second aspect of the Mangahewa development is operating expenditure. This is forecast to amount to $15 million per year. This translates to a direct $6 million boost to regional GDP and 30 FTE jobs. Once flow-on effects are taken into account the contribution to Taranaki's GDP increases to $9 million and 60 FTE jobs are created.[193] The direct benefit to New Zealand is estimated to be a $7 million boost to GDP and 30 FTE jobs. Once flow-on effects are taken into account these increase to $14 million to GDP and 80 FTE jobs.[194]

7.2.3 Royalties

Royalties from the Mangahewa development are expected to be about $45 million per year on average for the first 10 years of life of the field.[195]

7.2.4 Additional benefits

The benefits of the Mangahewa development extend far beyond the direct and flow-on effects of the capital and operating expenditure associated with the project. As noted earlier, the development has enabled Todd to sign a 10 year natural gas supply agreement with Methanex. This has enabled Methanex to continue its New Zealand operations, and consider expanding them. The combined projects will result in an increase in government revenue of up to $1.2 billion over 10 years. Increased production by Methanex also has the potential to increase throughput at Port Taranaki by 25 percent.[196]

[189] Leung-Wai, Jason, Dixon, Hugh (BERL Economics), January 2012, 'Economic Impact of Oil and Gas Investment in Taranaki and Nationally', (Report to Todd Energy), *BERL Economics*, p.16.

[190] *Ibid*, p. 4.

[191] *Ibid*, p.18.

[192] *Ibid*.

[193] *Ibid*, p. 19.

[194] *Ibid*, p. 20.

[195] *Ibid*, p. 21.

[196] Mikalovich, Sheryn eds. 'Portal', August 2012, *Port Taranaki*, p. 15. http://www.porttaranaki.co.nz/sites/default/files/publications/portal_magazine/portal_-_august_2012.pdf

7.3 Social Benefits

7.3.1 Contribution to community projects

The oil and gas industry contributes very substantially to the Taranaki and wider New Zealand communities each year.

Todd, its parent company, the Todd Corporation, and Todd family members have long been involved in philanthropy and sponsorship. The Todd Foundation, established in 1972 with funds gifted from family businesses, focuses its annual giving largely on the wellbeing of children and young people and made grants in 2011 of $4.8 million.

The Todd Corporation also makes substantial grants, usually in the form of sponsorships. Significant sponsorship arrangements in recent times have included:

> a Todd pledge of $2.5 million for the building of New Plymouth's Len Lye Centre, which will showcase the work and ideas of kinetic artist Len Lye. In addition Todd will provide $100,000 per annum for five years for an associated educational programme

> becoming a cornerstone sponsor of the international WOMAD (World of Music and Dance) festival held annually in New Plymouth

> $227,000 for Taranaki Coastguard's new rescue vessel, which is being built at an estimated cost of $1.2 million

> Todd's $80,000 per annum sponsorship arrangement with the New Plymouth District Council for naming rights of the city's Aquatic Centre, under an agreement started in 2006

> a two-year sponsorship deal between Nova Energy and the Wellington Phoenix Football Club, and

> a naming rights sponsorship arrangement with the Taranaki Kart Club's raceway facility at Waitara, Taranaki.

More modest one-off gifts or sponsorships have been made to community events, sports tournaments, and school functions and performances.

Todd retail companies also support Books in Homes, Truant-line, Life Education Trust and Road Safety education. Support for these programmes is complemented by involvement in a raft of school-based initiatives, including sports, prize-givings and funding school equipment in the communities in which Todd operates.

7.4 Environmental benefits

Natural gas plays an important role in minimising New Zealand's greenhouse gas emissions. Fossil fuels supplied 61 percent of New Zealand's primary energy supply in 2011.[197] Natural gas is the cleanest burning of the fossil fuels, emitting up to 50 percent less carbon dioxide than coal.[198] It is the next best thing to more renewable energy generation.

Todd is at the forefront of pursuing renewable energy options in New Zealand. It has significant investments in solar, hydro, geothermal and tidal energy projects. It also operates a landfill gas powered electricity generation plant near Wellington.

[197] Note: 77 percent of New Zealand's electricity supply was met by renewable energy sources in 2011. The electricity supply is a subset of the total energy supply. Ministry of Economic Development (NZ), 2012, 'Energy Data File', *Table A.2: Total Primary Energy Supply*, p. 10 and *Table G.2b: Net Electricity General by Fuel Type*, p. 109. http://www.med.govt.nz/sectors-industries/energy/pdf-docs-library/energy-data-and-modelling/publications/energy-data-file/energydatafile-2011.pdf

[198] US Environmental Protection Agency, 28 December 2007, 'Natural Gas', *How Does Electricity Affect the Environment?* http://www.epa.gov/cleanenergy/energy-and-you/affect/natural-gas.html

In addition to supplying a relatively clean energy source, the oil and gas sector makes a considerable effort to mitigate and offset the effect it does have on the environment. In the five years to 2007 the sector made capital investments in environmental protection and enhancements worth $91.3 million. The majority of this was invested in land and air quality management.[199]

Many oil and gas companies invest in biodiversity projects to benefit the environment and community. For example Shell Todd Oil Services is one of the original partners of the Herekawe Walkway project in New Plymouth. The project involves the community, corporates and councils, with the purpose of creating an all-weather walkway along the Herekawe Stream from suburban Spotswood to Back Beach. The stream has been bridged at two points and cleared of weeds and willows. The quality of its waters is being protected and improved by 1,500 metres of new riparian fencing to keep stock out and 10,000 new streamside plants.[200]

The oil and gas sector makes a considerable effort to mitigate and offset the effect it does have on the environment.

The Herekawe Walkway project developed from an initiative in 2003 by major companies that operate in the Herekawe's catchment – Dow AgroChemicals, Methanex and Shell Todd Oil Services. The project has grown to include contractor AJ Cowley, the Taranaki Regional Council, the New Plymouth District Council, the Taranaki Tree Trust and other groups.[201]

Evidence that the Taranaki environment is not undermined by the presence of the oil and gas industry or the use of hydraulic fracturing is seen in the accolades awarded to New Plymouth. In 2008, New Plymouth was named the world's most liveable small city by LivCom. It also won the world's best environmentally sustainable project for its coastal walkway.[202] North and South Magazine named New Plymouth the best city in New Zealand in 2008.[203] It is also notable that films such as the Hollywood blockbuster *The Last Samurai* have been shot in Taranaki expressly because of its scenery, and notwithstanding ongoing oil and gas operations.

Conclusion

The oil and gas sector generates significant economic benefits for New Zealand and helps meet the energy needs of households, businesses and industries. Hydraulic fracturing is an important tool for the sector in continuing to meet consumer needs as Maui and Kapuni wind down.

It is a major employer, especially in Taranaki, and makes substantial contributions to GDP and government revenue.

The sector has given rise to a number of significant spin-off industries, ranging from those who use its products as feedstock for their operations, to those who have been able to gain expertise and critical mass off the back of industry contracts.

As one of the cleanest burning fossil fuels, with significantly lower greenhouse gas emissions than coal, natural gas is the obvious, affordable, reliable transitional fuel as we move over time to affordable renewable sources of energy.

Tight gas resources are required to secure New Zealand's long term gas supply, and their production necessitates the use of hydraulic fracturing.

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[199] Wu, Jiani, Sanderson, Kel, June 2008, 'Community Investment in Environmental Improvements in Taranaki' (Report to: Taranaki Regional Council), *Business and Economic Research Limited (BERL)*, p. 21. http://www.trc.govt.nz/assets/Publications/state-of-the-environment-monitoring/enviro+investment.pdf

[200] Taranaki Regional Council, February 2009, 'Taranaki Where We Stand: State of the Environment Report 2009', *TRC*, p. 145. http://www.trc.govt.nz/assets/Publications/state-of-the-environment-monitoring/state-of-the-environment-report-200/full+report.pdf

[201] *Ibid.*

[202] The International Awards for Liveable Communities, 2012, 'The LivCom Awards'. www.livcomawards.com

[203] Taranaki Daily News Online, 11 October 2008, 'New Plymouth NZ's No 1 city'. http://www.stuff.co.nz/taranaki-daily-news/668034/New-Plymouth-NZs-No-1-city

Appendix

Appendix A – Panel of independent reviewers

This document has been reviewed by independent experts. Reviewers were not asked to endorse the report's conclusions and recommendations. They acted in a personal and not an organisational capacity.

Associate Professor Rosalind Archer, Department of Engineering, University of Auckland

Rosalind Archer has a PhD in Petroleum Engineering and a PhD minor in Geological and Environmental Science from Stanford University.

Dr Rob Jeffrey, Research Program Leader, Petroleum Engineering, Commonwealth Scientific and Industrial Research Organisation (CSIRO)

Dr Rob Jeffrey has Masters and Doctorate degrees in Geological Engineering from the University of Arizona, Tuscon.

Associate Professor Nicholas Harris, Department of Earth and Atmospheric Sciences, University of Alberta

Nicholas Harris has a PhD and an MSc from Stanford University.

Professor Val Pinczewski, Professor of Petroleum Engineering, School of Petroleum Engineering, University of New South Wales

Val Pinczewski has a BE in Chemical Engineering and a PhD from the University of New South Wales.

Professor Richard Selley Emeritus Professor of Petroleum Geology and a Senior Research Fellow, Imperial College London

Richard Selley has a PhD in Geology from London University/ DIC, Geology, Imperial College and a Hon. DSc. from Kingston University.

Professor Zoe Shipton, Department of Civil Engineering, University of Strathclyde

Zoe Shipton has a PhD in Geology from the University of Edinburgh, and has held previous lectureships at the University of Glasgow and Trinity College, Dublin.

Associate Professor Michael Hannah, School of Geography, Environment, Earth Sciences, Victoria University of Wellington

Mike Hannah has a PhD in Palaeontology from the University of Adelaide.

Michael Holm Partner, Atkins Holm Majurey

Mike Holm has an LLB (Hons), an MSc in Resource Management (Distinction) from the University of Canterbury, and an LLM in Environmental Law from George Washington University.

Appendix B - Todd competency profile

Name	Current and Previous Roles	Relevant experience and project involvement track record
Paul Moore Executive Vice President, Upstream Energy and Resources, Todd Corporation and MD/CEO Todd Energy	> Todd Energy MD/CEO (1 year) > Otto Energy: (2 years) MD/CEO > Woodside (3 years): Executive Vice President of Northern & Emerging LNG, Executive Vice President Development > Santos (4 years): Vice President Development Projects and Technical Services, GM Western Australia > Fletcher Challenge Energy (11 years): Pohokura Field Development Manager, Operations and Engineering Manager, Brunei, Brunei Business Development Manager, NZ Field Development Manager, Director Maui Development Ltd 5 years. Manager Offshore Mining Company Ltd. > Shell International (9 years): Petroleum Engineer with operational postings in North Sea, Somalia, NZ, Spain and Tunisia.	> 30 years' experience in the exploration and production business including: > Todd Energy: MD/CEO Todd Energy. Accountabilities include ongoing operated operations at McKee/Mangahewa involving drilling, completions, projects, production and reservoir management. > Otto Energy: MD/CEO. Company turnaround, operated activities included Philippines deepwater seismic and land well drilling. Acquisition of Vitol Galoc interests and FPSO offshore operatorship handover planning. Various non-operated activities in Turkey, Argentina and Italy. > Woodside: Executive Vice President leading drilling, completion and subsea operations. Annual spend circa $A2bn drilling + completions and A$0.7bn subsea; 5-7 offshore rigs drilling circa 60 wells pa. Relevant roles included Member of Executive Committee, Business Operating Committee and New Opportunities Committee, functional head of developments, Director of Browse and Sunrise Business Units, Oceanway LNG terminal USA offshore infrastructure project. Drilling and completions operations were both onland (Libya) and offshore (Australia, Africa and GoM). > Santos: Vice President with responsibility for drilling and completions. Annual spend circa A$600mm. Annual operated well count 175 (155 onshore and 20 offshore) included full time frac team working in Cooper basin. Relevant roles included member of Santos leadership team, responsible for 4 offshore field development projects (Mutineer/Exeter, Casino, Maleo and Oyong). Four non operated developments (Bayu Undan, John Brookes, Minerva, and Patricia/Balleen). General Manager Western Australia, running offshore operated exploration appraisal and developments. > Fletcher Challenge Energy: Petroleum Engineering and Operations Manager with responsibility for Brunei offshore drilling (3 offshore wells including HPHT). Relevant roles included Pohokura discovery successfully delivering seismic acquisition/processing, appraisal drilling, reservoir characterisation, concept development studies and gas/liquids marketing evaluations via leadership of a multi-disciplinary team. Brunei development led appraisals and engineering screening studies of two operated offshore marginal discoveries and of undrilled prospects. NZ Development Manager included reservoir development of TAWN fields, McKee and Kaimiro. Fracking Director of Maui Development Ltd for 5 years including Maui B and FPSO oil development. > Shell International: Production Technologist (subset of Petroleum Engineering) in Shell UK Expro Aberdeen (Production Operations and HPHT well testing) and London (Field Development Project) Teams, included 1 year as PE secondee in various upstream audits. 3

Name	Current and Previous Roles	Relevant experience and project involvement track record
		years rig based as Wellsite Petroleum/Drilling Engineer in Somalia, NZ, Spain, and Tunisia. > Trained as Petroleum Engineer on Shell Graduate Training Programme in The Hague 1982. > Qualifications: MBA, BSc Hons (Civ Eng) 2:1 Diploma of Eng. C.Eng (UK), Eur Ing, Fellow IMMM (UK), Fellow AICD. SPE Member 30 years.
Andrew Clennett General Manager Operations	> Todd Energy (March 2012): General Manager Operations > Woodside Energy (8 years): Drilling & Development Engineering Manager, Lead Drilling Engineer, Development C > Maersk Oil & Gas (3 years): Senior Drilling Engineer > Consultant Drilling Engineer (4 years): Clients included Petrobras, STOS, Woodside > Esso Australia (Exxon) (3 years): Drilling Engineer	> 18+ years' experience in the exploration and production business including: > Todd Energy: General Manager – Operations responsible for drilling and completions, field project execution and production operations. Activities have included recent management oversight of Todd Energy's successful hydraulic fracture stimulation program on the Mangahewa field (Mangahewa-11 and Mangahewa-5). > Woodside Energy: Drilling and Development Engineering Manager accountable for all development well engineering and drilling engineering elements of Woodside Energy's global operations and projects. Specific activities included oversight for design and safe execution of HPHT exploration wells, multi-zone hydraulic fractured completions, multilateral wells, high rate gas wells, remote actuated zonal completions - for both onshore and offshore wells. Accountable for regulatory design compliance, management systems, competency and well integrity. > Woodside Energy: Lead Drilling & Development Engineer for Woodside's Australian oil business and African business. Oversight of design and execution of onshore and offshore wells including single and multi-zone hydraulic fractured completions. > Woodside: Senior Drilling Engineer / Wellsite Manager responsible for design and execution of deepwater exploration and development wells including multi-zone hydraulic fractured completions, utilising DP Semi submersibles and drillships. > Maersk Oil and Gas: Senior Drilling Engineer responsible for the design and execution of extended reach offshore development wells requiring 12-18 zones hydraulic fracture stimulations utilising Jack-ups in the Danish North Sea. > Drilling Engineering Consultant: Clients included Inpex, Petrobras, Shell, Woodside, involving drilling project management, well designs, project engineering for onshore and offshore wells including successful execution of operations in sensitive ecological environments. > Esso Australia: Drilling Engineer designing and executing oil development projects in the Gippsland Basin. > Qualifications: BEng (Hons) (Mechanical/Electrical) University of Tasmania, Australia, SPE member.

Name	Current and Previous Roles	Relevant experience and project involvement track record
Winfred Boeren Development Manager	> Todd Energy: General Manager Development > Todd Energy (10 years): Onshore Assets Manager > STOS (2 years): Head of Planning & Economics > Shell International (13 years): Well-site Petroleum Engineer, Production > Technologist, Senior Production Technologist, Well Development Team Leader with operational postings in Oman (PDO), New Zealand (STOS) and the UK (Shell Expro)	> 25 years' experience in the exploration and production business including: > Todd Energy: Asset Manager for Todd's McKee and Mangahewa fields. Initially (2002-2005) this involved guiding/steering the Operator (STOS) after Todd had purchased these assets. This was followed by project managing the operator transition to Todd (2005-2006), and subsequently managing all McKee and Mangahewa activities/operations. The latter included definition and execution of appraisal and development activities in these fields, including drilling and hydraulic fracturing of various Mangahewa wells with active engagement with the operator (STOS) on the tight gas appraisal activities (including hydraulic fracturing in KA-4, -5, and -18). > Todd Energy: Asset Manager for Todd's 50% shareholding in the Kapuni field, with active engagement with the Operator (STOS) on the tight gas appraisal activities (including hydraulic fracturing in KA-4, -5, and -18). > Shell Expro: Well Development Team Leader for drilling and well entry activities on Brent Alpha & Bravo. > STOS: Senior Production Technologist for all STOS' operations/fields. > STOS: Production Technologist for Kapuni, which included production optimisation, identification and planning workovers, the design and execution of the KA-8 and KA-06 skin-frac treatments. > STOS: Maui-B Oil Project (FPSO development) – petroleum engineering representative in the project team. > PDO: Production technologist for all oil and gas fields in the Qarn Alam area (central Oman), which included the Saih Rawl, Barik and Saih Niyada fields. These fields were being appraised for their deep gas potential (incl. the application of hydraulic fracturing), which has subsequently resulted on the Oman LNG development. > Qualifications: M.Sc. in Petroleum Engineering at Technical University Delft (The Netherlands). SPE member for 28 years.
Bill Armstrong Environmental Manager	> Todd Energy (6 years): Environmental Manager > Cawthron Institute: Environmental Scientist > Commission for the Environment:	> Over 30 years' experience in environmental management in New Zealand, much of that relating to the effects of development projects > Extensive knowledge of onshore and offshore regulatory regime including the Resource Management Act, HSNO Act, Maritime Transport Act, Conservation Act and EEZ & Continental Shelf Act regime.

Name	Current and Previous Roles	Relevant experience and project involvement track record
	Environmental Analyst > Parliamentary Commissioner for the Environment (5 years): Senior Investigating Officer > Armstrong Associates Environmental Consultants (6 years): Principal > MWH International Environmental Consulting Services (7 years): Manager	> Extensive experience with effects assessment, environmental mitigation, and consenting. > Wide knowledge of Government policy environment. > Six years managing Todd Energy's consenting and compliance obligations in respect of its onshore E&P operations in Taranaki.
Brett Nicol Production Technologist and Well Services Superintendent	> Todd Energy (2006-2012): Production Technologist and Well Services Superintendent for McKee and Mangahewa fields > RWE DEA (early 2006): Testing & Completion Superintendent, Egypt > British Gas (1999-2005): Senior Production Technologist/PE/Engineering Liaison with REPSOL YPF working on high pressure gas projects in Tunisia, Trinidad and Bolivia > Helix RDS Production Technologies: Senior Production Technologist working on British Gas, Kerr McGee, Talisman, Chevron Texaco, Amerada Hess on North Sea and other projects in Baku, Caspian Sea, Tunisia and Venezuela > SUCO Deminex: Offshore Drilling and Workover Superintendent, Zeit Bay, Egypt > Schlumberger Anadrill: MWD/LWD Engineer in NZ and Indonesia	> 32 years' experience in the exploration and production business including: > Todd Energy: Production Technologist and Well Services Superintendent for Todd's McKee and Mangahewa fields. This involved well designs, sourcing materials and completion, hydraulic fracturing stimulation and testing programmes and supervision. > RWE DEA (Egypt): Testing and completion of the highest pressure oil well ever found on land in the Nile Delta Dissouq PPL. > British Gas (Tunisia, Bolivia and Trinidad): Newly acquired Bolivian asset evaluation. Workover designs to triple gas exports from 50-150MMscfd. New well designs including first cemented monobore wells in Bolivia. Completions and testing supervision. Engineering liaison between BG and Repsol YPF for development, completion and testing of the Margarita and Huacaya high pressure gas fields (8,000psi SITHP). Supervised Margarita-4 testing to 70MMscfd gas rate. > NZOG: Exploration well operations, completions and testing engineer. Ngatoro field development including introduction of the first jet-pumps to NZ. > Petrocorp Exploration (1985-1991): Operations Engineer for Waihapa-2, -3, -4 and -5 including completions, acid stimulations and testing. McKee round 2 & 3 infill drilling, completions and testing. Kaimiro-1 hydraulic fracturing programme and field supervision. Kaimiro shallow completions and testing. > NL Petroleum Services (1980-1984): Drilling Fluid Engineer in North Africa and Drilling Engineer in the Dutch and Danish sectors of the North Sea. > Qualifications: BSc in Applied Physics, Auckland University. Society of Petroleum Engineers member for 26 years.

Name	Current and Previous Roles	Relevant experience and project involvement track record
	> Fletcher Challenge Energy: Production Engineer > NZOG: Completion and Testing Supervisor, McKee, Kaimiro, Ngatoro, Waihapa, Tariki > Petrocorp Exploration: Operations Engineer and later Production Technologist	
Lindsay Downey P.Eng. Senior Completions Engineer	> Todd Energy (September 2012): Senior Completions Engineer > BG International (3 years): Principal Completions Engineer, QGC in Brisbane. BG Canada in Calgary > Talisman Energy (4 years): Senior Completions Engineer > Consultant Completions Engineer (4 years): Clients included Penn West, Apache, Talisman > Devon Energy (8 years): Senior Petroleum Engineer	> 28+ years' Petroleum engineering experience in the oil and gas industry including: > Todd Energy: Senior Completions Engineer responsible for completions and workover engineering and field project execution. > QGC a BG Group Business: Principal Completions Engineer responsible for completion engineering in both CSG and deep, tight gas exploration program. Responsible for regulatory design compliance, management systems, competency and well integrity. > BG Canada: Senior Completions Engineer. Led completion cngineering activities for Western Canadian Foothills HT HP sour gas exploration program. Conducted detailed completion engineering evaluations into undeveloped Canadian shale plays for grassroots exploration project. > Talisman: Senior Completions Engineer responsible for design and execution of Canadian deep basin tight gas development wells including multi-zone hydraulic fractured completions. Designed multi-stage fracture treatments on horizontal wells in Canada and the USA. > Completion Engineering Consultant: Clients included PennWest, Apache & Talisman, involving completion and workover project management, stimulation designs, project engineering for large shallow gas projects, re-frac projects and multi-year completion and workover projects on shallow, sour gas well on Lake Erie. > Devon Energy: Senior Petroleum Engineer responsible for all engineering activities within various asset areas in Western Canada. Disciplines included reservoir, drilling, completions, facilities and production. > Qualifications: B.Sc. Degree in Petroleum Engineering. P.Eng. Montana College of Mineral Sciences and Technology, APEGGA and SPE member.
AWT International, Technical support		Todd's extensive in-house expertise is complemented by AWT International, a specialist engineering consultancy who provide highly specialised technical support to Todd's hydraulic

Name	Current and Previous Roles	Relevant experience and project involvement track record
		fracturing operations. AWT has an impeccable HSE record and supplies top class staff to oil and gas operations throughout the world, with a network of expertise and experience covering the full exploration and development process. This includes: > Drilling & Completions > Exploration & Subsurface > HSEQ > Operations > Project Engineering > Petroleum & Production Engineering > Subsea > Well Testing & Well Servicing AWT's depth and range of experience ensures Todd Energy always has ready access to additional specialised technical advice and support.

Appendix C - Service Provider Capability

Background

Because hydraulic fracturing is a highly specialised activity, most operating companies such as Todd Energy (Todd) use a specialist service provider to carry out hydraulic fracturing operations. As the operator, Todd is concerned to ensure that its service providers have the right skills and experience to carry out operations safely and effectively, and in a manner that will not harm the environment.

Service provider selection

Todd manages contractors within a Well Entry Quality Assurance Plan which is based on the general principles of quality management. This plan identifies the management tools to assess the competency of contractors and their ability to meet Todd's requirements.

Todd uses the Todd Energy Contractor Pre-award HSE assessment tool to begin the quality assessment of critical service providers and the particular services required for our program. This develops into a quality assurance audit which includes onsite assessment of the service provider's business processes. This involves matching the CV's of their employees to their task competency and discussions with key employees. Equipment, including certification and test documents, well stimulation materials storage and handling, logistics and waste minimisation are all reviewed. Health, safety and environmental processes are also evaluated and reviewed.

The service provider

Todd has selected Baker Hughes Pressure Pumping as its service provider for hydraulic fracturing in New Zealand.

Baker Hughes is a US company with its corporate head office located in Houston, Texas. It is a public company and is listed on the New York Stock Exchange. Baker Hughes is a diversified oilfield service provider. In addition to pressure pumping its other products and services include drilling, evaluation and fluids; completion, production and chemicals; and reservoir development services.

Baker Hughes employs 58,000 people in more than 80 countries and has major offices in the United Kingdom, Singapore, Dubai, Louisiana, Houston, Italy, and Kuala Lumpur. It also has a number of dedicated innovation and research centres located around the world. The company is administered in two hemispheres; an eastern hemisphere structure comprising five regions (Europe, Africa, Middle East, Asia Pacific and Russia/Caspian), and a western hemisphere with four regions (Canada, US Land, US Gulf and Latin America). Each region is subdivided into "Geo Markets" of which Australasia is one. Within the Australasian Geo Market, Baker Hughes has offices located in all major oil and gas centres, including New Plymouth.

Baker Hughes was incorporated in 1987 when Baker International and the Hughes Tool Company merged. The history of both companies in the oil and gas sector dates back more than 100 years. Baker Hughes has operated in New Zealand since 1999, and Baker Hughes Pressure Pumping (formerly BJ Services), which is the product line responsible for hydraulic fracture treatment, has been operating in New Zealand since 2005.

Baker Huges has continued to acquire and integrate other specialist oilfield service companies. Acquisition of companies such as Brown Oil Tools, CTC, EDECO, Elder Oil Tools, Milchem and Newpark, EXLOG, Eastman Christensen and Drilex, Teleco, Tri-State and Wilson, Centrilift, Aquaness, Chemlink and Petrolite, and Western Atlas, has ensured that Baker Hughes remain at the cutting edge of oilfield technology.

Performance

Baker Hughes is a leading provider of field development and production enhancement services, including well stimulation, cementing, sand control, coiled tubing, completion tools and fluids, down hole tools, and casing and tubular running services for new oil and natural gas wells and in remedial work on existing wells. They also offer production enhancement solutions, such as engineered operations in formation damage removal, fracture stimulation and water conformance engineering.

The company pioneered the modification of polymer concentrate recipes for fracturing fluids in the early 1990s to help ensure the safe delivery of treatment fluids in sensitive environments, such as those encountered in the North Sea, the Gulf of Mexico, and on Alaska's North Slope.

A similar effort was implemented for water-based fracture fluids used in land operations in the United States when Baker Hughes entered into an agreement with the US Environmental Protection Agency (EPA) to help eliminate diesel-oil-based polymer concentrates used in coal seam gas fracturing operations. Baker Hughes then took the proactive step of replacing diesel oil with an environmentally benign mineral oil in numerous chemicals used as part of all water-based fracturing applications throughout the US.

Baker Hughes engineered services have also minimised their environmental footprint, by reducing the equipment footprint as well as the fluids and chemicals required for fracture stimulation. Similarly, some other systems' operations reduce the horsepower and footprint requirements for multistage fracturing operations by using coiled tubing (CT) to convey a sand jet perforating tool that perforates the casing without creating tortuosity or damage in the formation.

Safer chemistries, fewer chemical additives, and a smaller footprint greatly reduce risk to the environment. Equipment design also includes measures aimed at reducing the impact on the environment. All heavy-duty trucks built since 2000 are equipped with industrial or residential-grade mufflers for noise abatement and electronic engine controls to reduce exhaust emissions and improve efficiency. The high powered high pressure fracture pump units were designed to pack more horsepower into each unit, which also reduces local traffic impact in sensitive areas.

Local Baker Hughes teams are supported by regional technology teams and a corporate research and development centre that develops technology to meet global best practice. The US is the world leader in the development of hydraulic fracture technology due to the high frequency of hydraulic fracturing operations there. New Zealand operators continue to benefit from the knowledge and experience that Baker Hughes offer when they transfer their experience and capability to other markets.

The service producer management team and field workers

Baker Hughes conducts hydraulic fracturing services daily on a worldwide scale. The company has an extensive list of policies and standards to ensure consistent standards of service delivery. These focus on both field and office based activities and are strictly adhered to. In addition to this, Baker Hughes must follow Todd standards and procedures, as well as local regulatory requirements. The company has processes in place to implement best practice and capture any lessons learned and these are applied to support a process of continuous improvement.

Baker Hughes has an advanced competency based training program called CAP (Career Advancement Plan). There are various types of CAP available for personnel to participate in:

- OCAP – Operators Career Advancement Plan
- SCAP – Supervisor Career Advancement Plan
- TCAP – Technical Career Advancement Plan

Personnel start at level 1 and progress to level 3 through accumulation of points scored by completing the required training courses for each level and being assessed at field level. Each level of achievement is matched with promotion and salary increases. Those enrolled in OCAP (Operator) will progress to SCAP (Supervisor) at the completion of level 3 OCAP.

Field operating personnel are developed within their training matrix to meet the requirements of their tasks. As team members, they are continuously assessed while working and direct feedback from experienced co-workers reinforces best practice. Experience is developed and there is recognition of the importance in experience to deliver the required field performance.

Risk management

Risk analysis for hydraulic fracturing has been discussed by George King in his technical paper *SPE 152596*. This paper works to present the complex issues relating to the process of hydraulic fracturing.

Ultimately, oil and gas development is a partnership of land owners, regulators, operators, and integrated service company experts working together to minimise risks, ensure environmental stewardship, and efficiently recover energy resources.

Risk management starts with comprehensive reservoir analyses and feasibility studies, combining geological features, rock properties, offset well experiences, regulatory guidelines, and economic drivers to support a team of expert engineers designing:

- Efficient well placement across the field to maximise reservoir drainage and improve water management logistics.
- Proper well construction to ensure zonal isolation for the life of the well.
- Optimised hydraulic fracture stimulation treatments to responsibly maximise production and economic returns.
- Enhanced recovery technologies to delay production declines and extend well life.
- Safe and effective plugging and abandonment procedures at the end of the well's productive life.

Before commencing a hydraulic fracturing treatment, detailed treatment design is completed and a site inspection is done by Todd and Baker Hughes representatives. During this inspection the site layout is evaluated to create the safest way to conduct the work. Equipment layout and connection to the well is planned. When field operations commence:

- The hydraulic fracturing equipment is mobilised to the well site and interconnection of equipment completed and tested. Materials are loaded in the pre-designated storage areas in preparation for the mixing process.

- The chemicals used in hydraulic fracturing are decanted from drums, and if required, pre-mixed in plastic IBC tote containers. The blender is then pre-loaded with the totes required for the job and excess pre-mixed totes are then loaded onto trailers.

- The team meets to discuss all aspects of the treatment, the state of readiness and review contingencies that may arise. With the pumping check list complete, the well is ready for the hydraulic fracturing process to begin.

- The job commences with the pumping of the agreed pumping schedule. The well response to hydraulic fracturing is monitored as the schedule progresses. In some cases, real time decisions are made to increase or decrease the pumping schedule to achieve the best practice outcome. These changes can arise from variation in expected reservoir properties and from mechanical issues arising in the pumping system. The process is managed in real time to achieve the optimum outcome as new understanding arises during the job execution.

- After the treatment is finished all surface lines are flushed back to the tankage for subsequent approved disposal. To prevent spills during breaking the lines a drip tray is placed under the connection. The equipment is then racked and securely stored on the trailers. The cables for the treatment monitor van are reeled in and equipment is mobilised to the next wellsite. If mobilising back to base, then a pre-trip inspection is carried out. This involves checking over of tires, oils, wheel nuts and properly stored and secured equipment.

The fracturing equipment and surface lines used to transport fluids to the wellhead are inspected and pressure tested prior to the start of each fracture treatment. The equipment is pressure rated and continuous monitoring occurs during operations to ensure that pressures remain below the safety-rated pressure levels. Raw chemicals are maintained inside bundled secondary containment areas to catch any releases before they can migrate off the site.

Baker Hughes Pressure Pumping field employees receive fundamental training that includes environmental awareness, hazard awareness and reporting, chemical handling standards, and affirmation of each employee's "Stop Work" authority. This means any employee has the right to stop a job if they witness an unsafe situation. In addition, preventative maintenance is used to ensure that equipment is working properly and performing its intended function.

Hydraulic fracturing materials

Since the primary goal is to improve hydraulic fracturing performance, especially in low permeability reservoirs, Baker Hughes always seeks to understand the reservoir first, and this drives the choice of recommended fracturing fluids. This means joint technology efforts with Todd on optimising cost/performance efficiencies to use fracturing fluids that are appropriate for a given reservoir, in order to provide highly conductive proppant packs and highly productive wells.

Fracturing fluid is the most important component in the hydraulic fracturing process. Water and propping agent constitutes more than 97 percent of the solution. In addition to these main ingredients, there are small amounts of other materials involved, each of which plays a critical role in the process. Many of these materials can be found in food, beverages and household cleaning items. Regulators are made aware of those chemicals and have access to information they need regarding their safe use.

The following are examples of how Baker Hughes' continuous environmental improvement efforts have helped reduce the ecological impact of oilfield products and services:

- New highly efficient, patented systems have been developed that work with minimised polymer loading, further reducing their environmental impact by improving fracture fluid system performance. They decrease the overall fluid and associated chemical additive volumes required for proper proppant placement.

- To enhance the application of bacteria control products and understanding of best practices using this necessary technology, Baker Hughes has implemented a major bacteria–control initiative. Among the most environmentally acceptable oilfield bacteria-control additives are the biocides applied by Baker Hughes. Specifically designed "green" clay control additives are environmentally preferred substitutes to minimise clay swelling in stimulation applications. The additive chemistry is effective for clay treatment and has been used as a feed additive in the poultry industry for more than 50 years

- Flowback additives provided by Baker Hughes are proprietary surfactants for enhancing load water recovery and fracture cleanup. These environmentally preferred alternatives to common surfactants (comprised of fluorocarbons and hazardous solvents) have been field-proven to outperform those materials in well stimulation applications. These surfactants are compatible with all of Baker Hughes' water-based fracturing fluids

- Baker Hughes has pioneered the development of a system of qualification process to compare all products' technical and economic value; compatibility; and HSE performance. The top performers are packaged together in engineered combinations, such as the family of "slick water systems", which include environmentally preferred surfactants and bacteria, clay-control, and friction-reduction additives made with environmentally compliant oils. Work is ongoing to develop systems for recycling and reuse of fluids. Waste minimisation is a driver in this process selection

- The Baker Hughes' family of solid chemicals places long-lasting inhibitors, bacteria control additives and other chemicals on a solid matrix, which can then be added to proppant in a fracture stimulation treatment. As solid materials, the products eliminate the potential of surface liquid spills that could leach into groundwater or surface water

Hydraulic fracturing equipment

The equipment to perform hydraulic fracturing is usually truck mounted and portable, able to arrive at a well site and perform the service. The hydraulic fracturing process demands a high level of integrated equipment performance to operate continuously over the job duration. To perform hydraulic fracturing the following equipment is generally utilised:

1. Fluid storage tanks or equivalent water storage with the ability to deliver water at the process rate.

2. Manifolding of fluid storage to interconnect equipment.

3. Fracturing fluid hydration unit – this continuously mixes water and chemical concentrates to the dilution required as base gelled water for fracturing fluid:
    - Computer controlled additive pumps provide the constituents to the mix.
    - Chemical concentrates are stored in drums or small IBC storage tanks in preparation drums and IBC storage tanks are bunded according to the material.

4. Blender unit – continuously blends material and pumps at low pressure to the discharge manifold:
    - Mixes chemical additives (dry and liquid) to the base gel to create the fracture fluid.
    - Mixes solid proppant materials to the base gel continuously.
    - The process is computer controlled to proportion proppant into the gel to create slurry based on the job design.

5. Proppant storage unit – a mobile unit or portable bins are used to store and safely deliver propping agents to the blender unit by conveyor belt or gravity force.

6. Low pressure discharge manifold - distributes fracture fluid to the HP pump suctions

7. High pressure pumps - diesel powered positive displacement pumps raise the pressure of the frac fluid from 40 psi to the wellhead injection pressure (3,000 – 8,000 psi) and deliver fluid at the design rate (typically five cubic metres per minute) to the high pressure discharge manifold. This pump set of typically four pump units can provide 8,000 hydraulic horsepower to the process.

8. High pressure discharge manifold – this manifolds the high pressure pumps to deliver fluid to the wellhead.

9. High pressure wellhead manifold – this manifolds the temporary piping into the Christmas tree.

10. Data Acquisition System - connects all equipment on site, provides real time detailed information such as job pressures, pumping rate, chemical and proppant addition ratio and rates.

11. Process control equipment:
    - Computer monitoring and equipment control centre
        - Communications hub to all personnel operating the equipment
        - Design, execution and recording personnel to manage the treatment
    - Laboratory for measurement of fluid rheology and performance real time.

Health and Safety Policy

TODD

Our Health & Safety Vision:

"We will all have a safe workplace"

We believe that:

- No business objective will take priority over health and safety
- All incidents are preventable
- Whilst management have ultimate accountability, we all have responsibility for health and safety
- All personnel have the responsibility to stop any job they believe is unsafe or cannot be continued in a safe manner

To achieve this we will:

- Maintain and continually improve our Health, Safety and Environmental Management System
- Proactively identify hazards and unsafe behaviours and take all steps to manage these to as low as reasonably practicable
- Set targets for improvement and measure, appraise and report on our performance
- Assess and recognise the health and safety performance of employees and contractors
- Consult and actively promote participation with employees and contractors to ensure they have the training, skills, knowledge and resources to maintain a healthy and safe workplace
- Accurately report and learn from our incidents
- Support the safe and early return to work of injured employees
- Design, construct, operate and maintain our assets so that they safeguard people and property
- Require our contractors to demonstrate the same commitment to achieving excellence in health and safety performance
- Comply with relevant legislation, regulations, codes of practice and industry standards

Jon Young

Group Chief Executive Officer
Todd Corporation Limited

Date issued: 11 August 2011
Review date: 11 August 2013

Environmental Policy

TODD

Our Environmental Vision:

"We will operate in an environmentally responsible manner"

We believe that:

- Our environmental commitments are an integral part of our day to day activities
- We are responsible for achieving good environmental practices
- We can have a positive impact on our operating environments
- Environmental stewardship is the responsibility of all employees

To achieve this we will:

- Maintain and continually improve our Health, Safety and Environmental Management System
- Proactively identify hazards and unsafe behaviours and take all steps to manage these to as low as reasonably practicable
- Set targets for improvement and measure, appraise and report on our performance
- Continually review opportunities to improve our environmental performance
- Ensure employees have the necessary training, skills, knowledge and resources to fulfil their environmental responsibilities
- Efficiently use our natural and physical resources
- Design, construct, and maintain our assets, and manage our operations, with the goal of preventing environmental incidents
- Require our business partners and contractors to demonstrate a similarly high level of commitment to environmental performance
- Comply with all relevant environmental laws and regulations

Jon Young

Group Chief Executive Officer
The Todd Corporation Limited

Date issued: 11 August 2011
Review date: 11 August 2013

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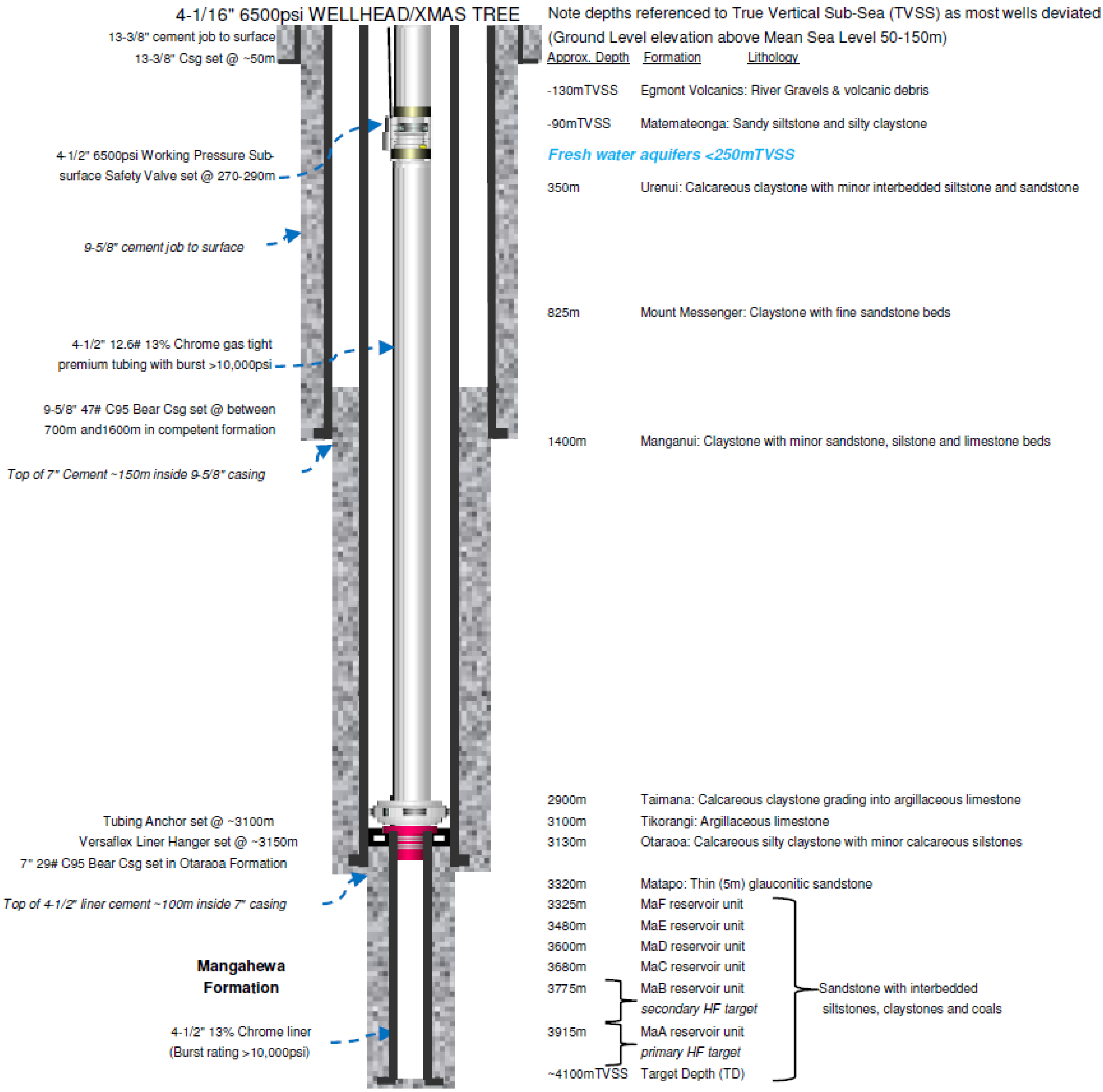
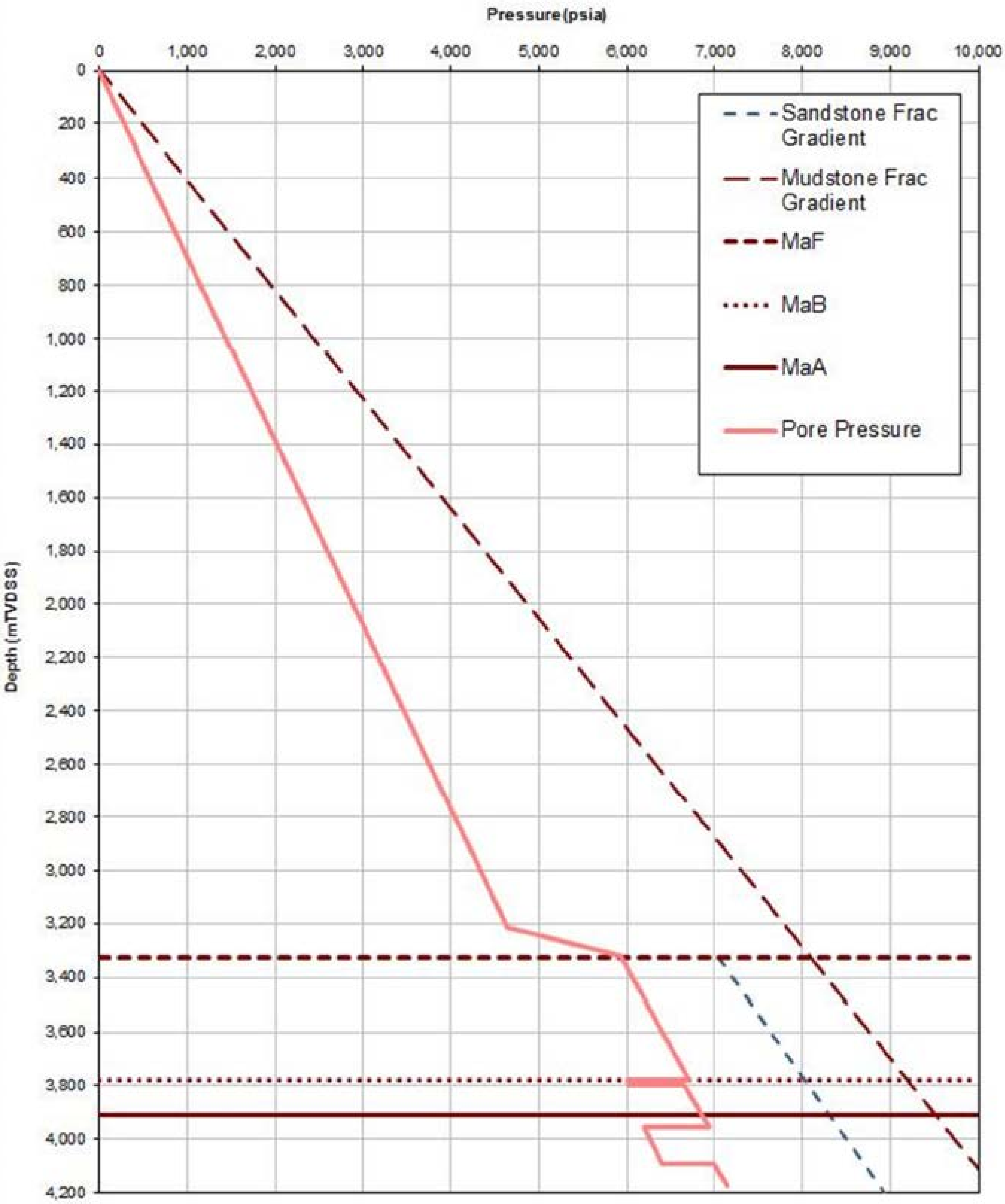
Appendix E – Well completion schematic

Mangahewa type gas wells

4 – 1/2” monobore construction



Pore Pressure and Frac Gradient Profile (TVDSS Plot)



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Web www.hill-labs.co.nz

ANALYSIS REPORT

Client:	Baker Hughes New Zealand Pty Ltd	**Lab No:**	1021825 SPv1
Contact:	S Forsyth	**Date Registered:**	30-Jun-2012
	C/- Baker Hughes New Zealand Pty Ltd	**Date Reported:**	09-Jul-2012
	PO Box 8347	**Quote No:**	49792
	NEW PLYMOUTH 4342	**Order No:**	4505415174
		Client Reference:	Frack fluid testing
		Submitted By:	S Forsyth

Sample Type: Aqueous

Sample Name:		Sample 1 12-May-2012 12:00 pm	Sample 2 13-May-2012 12:00 pm	Sample 3 14-May-2012 12:00 pm	Sample 4 16-May-2012 12:00 pm	Sample 5 18-May-2012 12:00 pm
Lab Number:		1021825.1	1021825.2	1021825.3	1021825.4	1021825.5
Individual Tests						
pH	pH Units	7.3	7.2	7.4	7.2	7.6
Salinity*		10.5	12.7	16.8	17.3	18.1
Total Suspended Solids	g/m^3	73	101	51	260	48
Total Dissolved Solids (TDS)	g/m^3	14,400	16,000	18,000	18,400	19,300
Chloride	g/m^3	4,000	5,400	8,500	8,200	8,200
Total Petroleum Hydrocarbons in Water, GC						
C7 - C9	g/m^3	< 0.15	0.66	0.35	31	0.17
C10 - C11	g/m^3	< 0.2	2.0	0.9	43	< 0.2
C12 - C14	g/m^3	0.8	13.9	3.6	73	0.8
C15 - C20	g/m^3	2.1	49	9.2	143	3.7
C21 - C25	g/m^3	0.6	17.4	4.5	73	1.9
C26 - C29	g/m^3	0.4	14.3	2.6	39	0.9
C30 - C44	g/m^3	< 0.3	16.0	2.0	28	0.4
Total hydrocarbons (C7 - C44)	g/m^3	4.2	114	23	430	8.0

Sample Name:		Sample 6 19-May-2012 12:00 pm				
Lab Number:		1021825.6				
Individual Tests						
pH	pH Units	7.6	-	-	-	-
Salinity*		18.8	-	-	-	-
Total Suspended Solids	g/m^3	7	-	-	-	-
Total Dissolved Solids (TDS)	g/m^3	20,000	-	-	-	-
Chloride	g/m^3	8,500	-	-	-	-
Total Petroleum Hydrocarbons in Water, GC						
C7 - C9	g/m^3	1.12	-	-	-	-
C10 - C11	g/m^3	< 0.2	-	-	-	-
C12 - C14	g/m^3	1.2	-	-	-	-
C15 - C20	g/m^3	4.4	-	-	-	-
C21 - C25	g/m^3	2.3	-	-	-	-
C26 - C29	g/m^3	1.2	-	-	-	-
C30 - C44	g/m^3	0.6	-	-	-	-
Total hydrocarbons (C7 - C44)	g/m^3	10.9	-	-	-	-

Analyst's Comments
Appendix No.1 - Total Petroleum Hydrocarbon Chromatograms Appendix No.2 - Total Petroleum Hydrocarbon Chromatograms

SUMMARY OF METHODS

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively clean matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis.

Sample Type: Aqueous

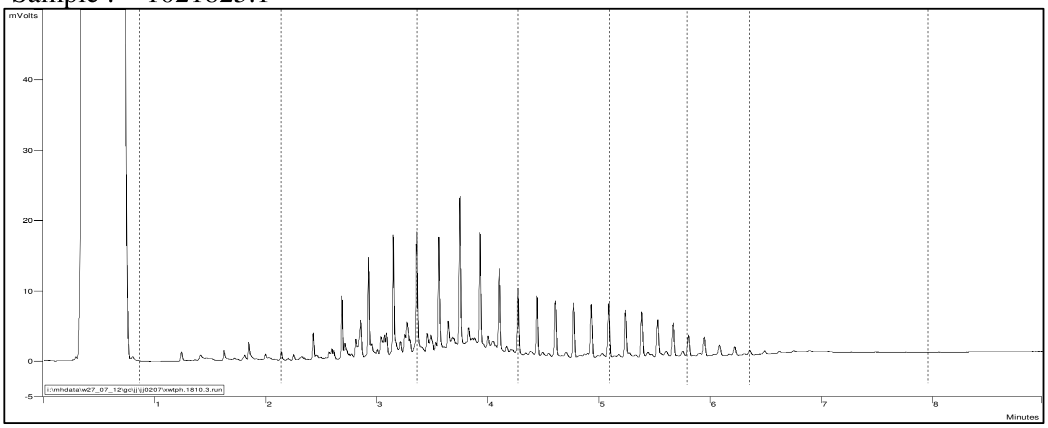
Test	Method Description	Default Detection Limit	Samples
Total Petroleum Hydrocarbons in Water, GC	Solvent extraction, GC-FID analysis US EPA 8015B/MfE Petroleum Industry Guidelines	-	1-6
Filtration, Unpreserved	Sample filtration through 0.45µm membrane filter.	-	1-6
pH	pH meter. APHA 4500-H^+ B 21^{st} ed. 2005.	0.1 pH Units	1-6
Salinity*	Meter, no temp. compensation. APHA 2520 B 21^{st} ed. 2005.	0.2	1-6
Total Suspended Solids	Filtration using Whatman 934 AH, Advantec GC-50 or equivalent filters (nominal pore size 1.2 - 1.5µm), gravimetric determination. APHA 2540 D 21^{st} ed. 2005.	3 g/m^3	1-6
Total Dissolved Solids (TDS)	Filtration through GF/C (1.2 µm), gravimetric. APHA 2540 C (modified; drying temperature of 103 - 105°C used rather than 180 ± 2°C) 21^{st} ed. 2005.	10 g/m^3	1-6
Chloride	Filtered sample. Ferric thiocyanate colorimetry. Discrete Analyser. APHA 4500 Cl^- E (modified from continuous flow analysis) 21^{st} ed. 2005.	0.5 g/m^3	1-6

These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.

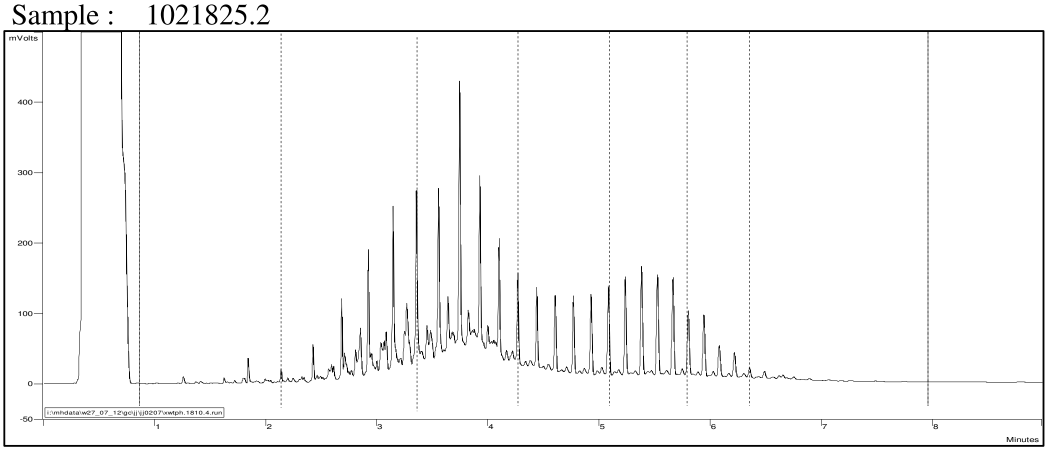
Samples are held at the laboratory after reporting for a length of time depending on the preservation used and the stability of the analytes being tested. Once the storage period is completed the samples are discarded unless otherwise advised by the client.

Ara Heron BSc (Tech)
Client Services Manager - Environmental Division

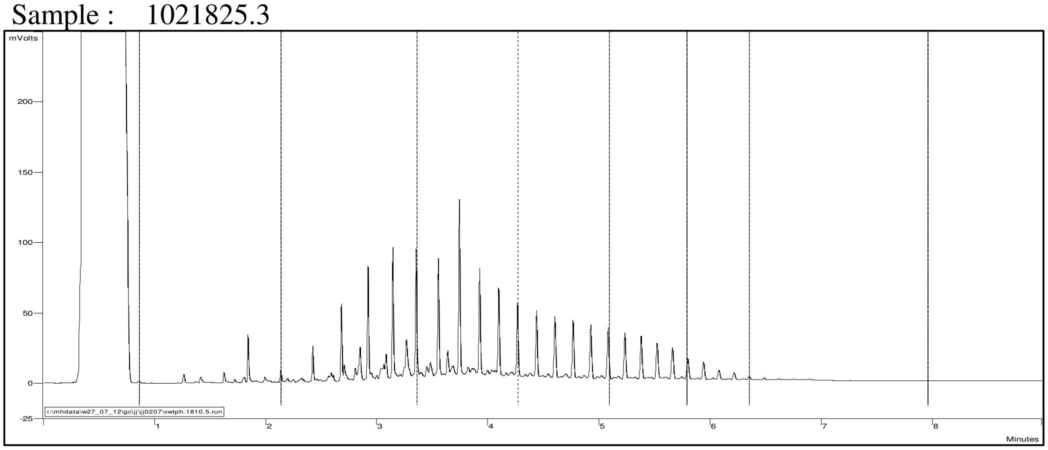
Sample : 1021825.1

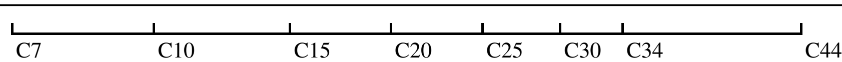


Sample : 1021825.2

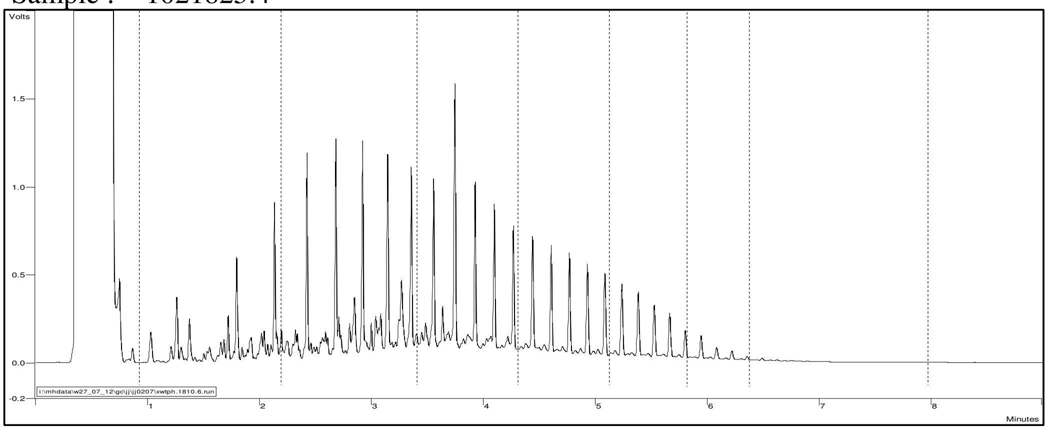


Sample : 1021825.3

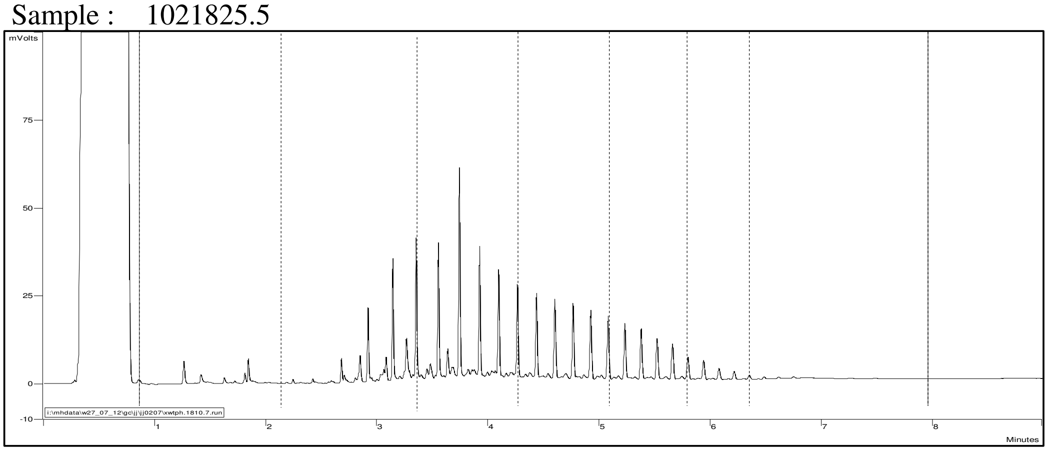




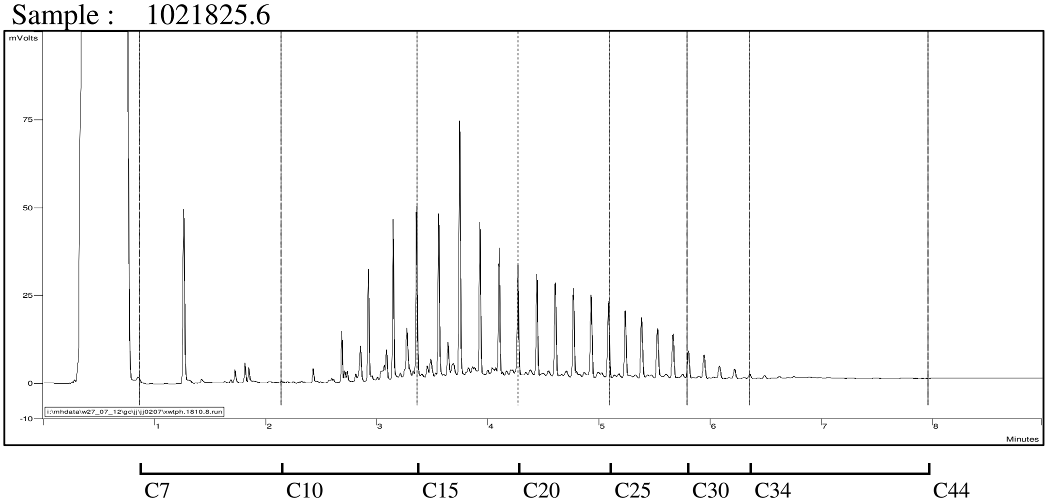
Sample : 1021825.4



Sample : 1021825.5



Sample : 1021825.6



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Web www.hill-labs.co.nz

ANALYSIS REPORT

Client:	BTW Company Ltd	**Lab No:**	1008025	SPv1
Contact:	Michael Collins	**Date Registered:**	16-May-2012	
	C/- BTW Company Ltd	**Date Reported:**	25-May-2012	
	PO Box 551	**Quote No:**	45045	
	NEW PLYMOUTH 4340	**Order No:**		
		Client Reference:	Tank Water	
		Submitted By:	Michael Collins	

Sample Type: Aqueous

	Sample Name:	MAN-C WWF 15-May-2012 11:00 am				
	Lab Number:	1008025.1				
Individual Tests						
pH	pH Units	6.9	-	-	-	-
Electrical Conductivity (EC)	mS/m	1,646	-	-	-	-
Total Dissolved Solids (TDS)	g/m³	11,300	-	-	-	-
Specific Gravity*	20°C/20°C	1.01	-	-	-	-
Hexavalent Chromium	g/m³	< 0.010	-	-	-	-
Total Potassium	g/m³	520	-	-	-	-
Total Sodium	g/m³	3,500	-	-	-	-
Chloride	g/m³	4,400	-	-	-	-
Total Nitrogen	g/m³	39	-	-	-	-
Nitrate-N + Nitrite-N	g/m³	0.08	-	-	-	-
Total Kjeldahl Nitrogen (TKN)	g/m³	39	-	-	-	-
Heavy metals, totals, trace As,Cd,Cr,Cu,Ni,Pb,Zn						
Total Arsenic	g/m³	< 0.011	-	-	-	-
Total Cadmium	g/m³	< 0.00053	-	-	-	-
Total Chromium	g/m³	0.030	-	-	-	-
Total Copper	g/m³	0.131	-	-	-	-
Total Lead	g/m³	0.24	-	-	-	-
Total Nickel	g/m³	0.025	-	-	-	-
Total Zinc	g/m³	0.78	-	-	-	-
Ethylene Glycol in Water						
Ethylene glycol*	g/m³	< 4	-	-	-	-
Methanol in Water - Aqueous Solvents						
Methanol*	g/m³	35	-	-	-	-
BTEX in Water by Headspace GC-MS						
Benzene	g/m³	3.1	-	-	-	-
Toluene	g/m³	3.5	-	-	-	-
Ethylbenzene	g/m³	0.33	-	-	-	-
m&p-Xylene	g/m³	2.2	-	-	-	-
o-Xylene	g/m³	1.04	-	-	-	-
Glutaraldehyde in Water by DNPH & LCMSMS						
Glutaraldehyde*	g/m³	< 3	-	-	-	-
Total Petroleum Hydrocarbons in Water						
C7 - C9	g/m³	6.5	-	-	-	-
C10 - C14	g/m³	680	-	-	-	-
C15 - C36	g/m³	2,600	-	-	-	-
Total hydrocarbons (C7 - C36)	g/m³	3,200	-	-	-	-

Analyst's Comments

Appendix No.1 - Total Petroleum Hydrocarbon Chromatograms

SUMMARY OF METHODS

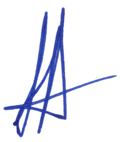
The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively clean matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis.

Sample Type: Aqueous

Test	Method Description	Default Detection Limit	Samples
Acetaldehyde and Glutaraldehyde in Water extraction,Trace*	DNPH derivatisation, extraction, HPLC.	-	1
Heavy metals, totals, trace As,Cd,Cr,Cu,Ni,Pb,Zn	Nitric acid digestion, ICP-MS, trace level	-	1
Ethylene Glycol in Water*	Direct injection, dual column GC-FID	-	1
Methanol in Water - Aqueous Solvents*	Direct injection, dual column GC-FID	-	1
BTEX in Water by Headspace GC-MS	Headspace GC-MS analysis, US EPA 8260B	-	1
Glutaraldehyde in Water by DNPH & LCMSMS*	DNPH derivatisation, extraction, LCMSMS	-	1
Total Petroleum Hydrocarbons in Water	Hexane extraction, GC-FID analysis US EPA 8015B/MfE Petroleum Industry Guidelines	-	1
Filtration, Unpreserved	Sample filtration through 0.45μm membrane filter.	-	1
Total Digestion	Boiling nitric acid digestion. APHA 3030 E 21st ed. 2005.	-	1
Total Kjeldahl Digestion	Sulphuric acid digestion with copper sulphate catalyst.	-	1
pH	pH meter. APHA 4500-H^+ B 21st ed. 2005.	0.1 pH Units	1
Electrical Conductivity (EC)	Conductivity meter, 25°C. APHA 2510 B 21st ed. 2005.	0.1 mS/m	1
Total Dissolved Solids (TDS)	Filtration through GF/C (1.2 μm), gravimetric. APHA 2540 C (modified; drying temperature of 103 - 105°C used rather than 180 ± 2°C) 21st ed. 2005.	10 g/m^3	1
Specific Gravity*	Calculation: weight of sample / weight of equivalent volume of water at 20°C. Gravimetric determination.	0.01 20°C/20°C	1
Hexavalent Chromium	Diphenylcarbazide colorimetry. Discrete Analyser. APHA 3500 Cr B (modified from manual analysis) 21st ed. 2005.	0.010 g/m^3	1
Total Potassium	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 21st ed. 2005.	0.053 g/m^3	1
Total Sodium	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 21st ed. 2005.	0.021 g/m^3	1
Chloride	Filtered sample. Ferric thiocyanate colorimetry. Discrete Analyser. APHA 4500 Cl^- E (modified from continuous flow analysis) 21st ed. 2005.	0.5 g/m^3	1
Total Nitrogen	Calculation: TKN + Nitrate-N + Nitrite-N.	0.05 g/m^3	1
Nitrate-N + Nitrite-N	Total oxidised nitrogen. Automated cadmium reduction, flow injection analyser. APHA 4500-NO_3^- I (Modified) 21st ed. 2005.	0.002 g/m^3	1
Total Kjeldahl Nitrogen (TKN)	Total Kjeldahl digestion, phenol/hypochlorite colorimetry. Discrete Analyser. APHA 4500-N_{org} C. (modified) 4500 NH_3 F (modified) 21st ed. 2005.	0.10 g/m^3	1

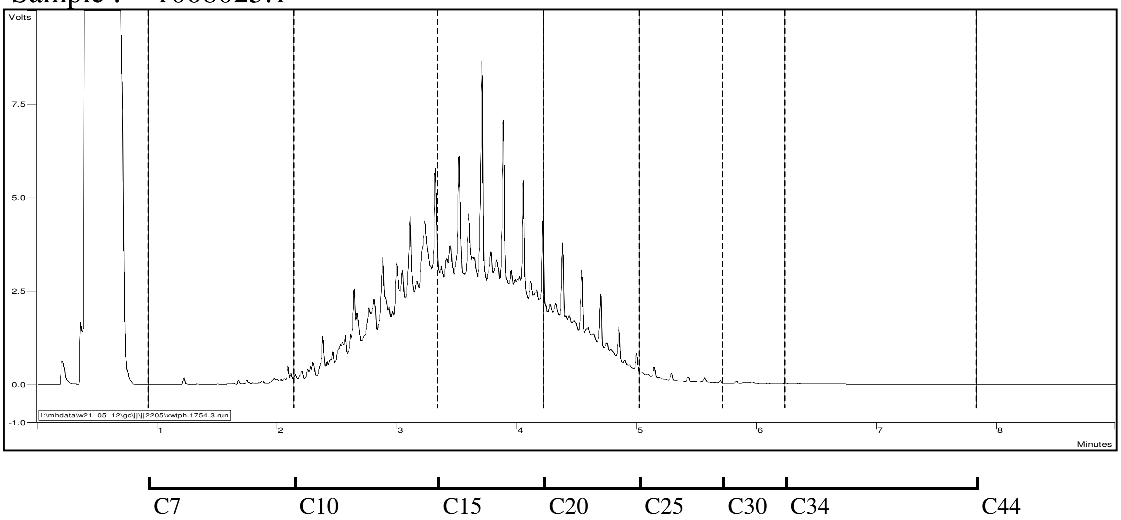
These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.

Samples are held at the laboratory after reporting for a length of time depending on the preservation used and the stability of the analytes being tested. Once the storage period is completed the samples are discarded unless otherwise advised by the client.



Ara Heron BSc (Tech)
Client Services Manager - Environmental Division

Sample : 1008025.1



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ANALYSIS REPORT

Client:	BTW Company Ltd	**Lab No:**	970482 SPv2
Contact:	D Riley	**Date Registered:**	21-Jan-2012
	C/- BTW Company Ltd	**Date Reported:**	21-Feb-2012
	PO Box 551	**Quote No:**	45045
	NEW PLYMOUTH 4340	**Order No:**	
		Client Reference:	Tank Water
		Submitted By:	D Riley

Amended Report

This report replaces an earlier report issued on the 02 Feb 2012 at 2:11 pm
PAH analysis added at clients request.

Sample Type: Aqueous

Sample Name:		Man - D WWF 20-Jan-2012 3:00 pm				
Lab Number:		970482.1				
Individual Tests						
pH	pH Units	9.1	-	-	-	-
Electrical Conductivity (EC)	mS/m	1,984	-	-	-	-
Total Dissolved Solids (TDS)	g/m^3	13,600	-	-	-	-
Specific Gravity*	20°C/20°C	1.00	-	-	-	-
Hexavalent Chromium	g/m^3	< 0.10 #1	-	-	-	-
Total Potassium	g/m^3	580	-	-	-	-
Total Sodium	g/m^3	4,700	-	-	-	-
Chloride	g/m^3	5,600	-	-	-	-
Total Nitrogen	g/m^3	22	-	-	-	-
Nitrate-N + Nitrite-N	g/m^3	0.005	-	-	-	-
Total Kjeldahl Nitrogen (TKN)	g/m^3	22	-	-	-	-
Heavy metals, totals, trace As,Cd,Cr,Cu,Ni,Pb,Zn						
Total Arsenic	g/m^3	< 0.011	-	-	-	-
Total Cadmium	g/m^3	< 0.00053	-	-	-	-
Total Chromium	g/m^3	< 0.0053	-	-	-	-
Total Copper	g/m^3	< 0.011	-	-	-	-
Total Lead	g/m^3	< 0.0011	-	-	-	-
Total Nickel	g/m^3	0.0058	-	-	-	-
Total Zinc	g/m^3	0.027	-	-	-	-
Ethylene Glycol in Water						
Ethylene glycol*	g/m^3	< 4	-	-	-	-
Methanol in Water - Aqueous Solvents						
Methanol*	g/m^3	< 2	-	-	-	-
BTEX in Water by Headspace GC-MS						
Benzene	g/m^3	0.0188	-	-	-	-
Toluene	g/m^3	0.026	-	-	-	-
Ethylbenzene	g/m^3	0.0024	-	-	-	-
m&p-Xylene	g/m^3	0.011	-	-	-	-
o-Xylene	g/m^3	0.0050	-	-	-	-
Glutaraldehyde in Water by DNPH & LCMSMS						
Glutaraldehyde*	g/m^3	< 0.03	-	-	-	-
Polycyclic Aromatic Hydrocarbons Screening in Water, By Liq/Liq						
Acenaphthene	g/m^3	< 0.00010	-	-	-	-
Acenaphthylene	g/m^3	< 0.00010	-	-	-	-

Sample Type: Aqueous						
Sample Name:		Man - D WWF 20-Jan-2012 3:00 pm				
Lab Number:		970482.1				
Polycyclic Aromatic Hydrocarbons Screening in Water, By Liq/Liq						
Anthracene	g/m³	< 0.00010	-	-	-	-
Benzo[a]anthracene	g/m³	< 0.00010	-	-	-	-
Benzo[a]pyrene (BAP)	g/m³	< 0.00010	-	-	-	-
Benzo[b]fluoranthene + Benzo[j] fluoranthene	g/m³	< 0.00010	-	-	-	-
Benzo[g,h,i]perylene	g/m³	< 0.00010	-	-	-	-
Benzo[k]fluoranthene	g/m³	< 0.00010	-	-	-	-
Chrysene	g/m³	< 0.00010	-	-	-	-
Dibenzo[a,h]anthracene	g/m³	< 0.00010	-	-	-	-
Fluoranthene	g/m³	< 0.00010	-	-	-	-
Fluorene	g/m³	< 0.0002	-	-	-	-
Indeno(1,2,3-c,d)pyrene	g/m³	< 0.00010	-	-	-	-
Naphthalene	g/m³	< 0.0005	-	-	-	-
Phenanthrene	g/m³	< 0.0004	-	-	-	-
Pyrene	g/m³	< 0.0002	-	-	-	-
Total Petroleum Hydrocarbons in Water						
C7 - C9	g/m³	< 0.10	-	-	-	-
C10 - C14	g/m³	< 0.2	-	-	-	-
C15 - C36	g/m³	0.6	-	-	-	-
Total hydrocarbons (C7 - C36)	g/m³	< 0.7	-	-	-	-

Analyst's Comments

#1 Severe matrix interferences required that a dilution be performed prior to analysis of sample 970482.1 resulting in a detection limit higher than that normally achieved for the Cr6s analysis.

Appendix No.1 - Total Petroleum Hydrocarbon Chromatograms

SUMMARY OF METHODS

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively clean matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis.

Sample Type: Aqueous

Test	Method Description	Default Detection Limit	Samples
Acetaldehyde and Glutaraldehyde in Water extraction,Trace*	DNPH derivatisation, extraction, HPLC.	-	1
Heavy metals, totals, trace As,Cd,Cr,Cu,Ni,Pb,Zn	Nitric acid digestion, ICP-MS, trace level	-	1
Ethylene Glycol in Water*	Direct injection, dual column GC-FID	-	1
Methanol in Water - Aqueous Solvents*	Direct injection, dual column GC-FID	-	1
BTEX in Water by Headspace GC-MS	Headspace GC-MS analysis, US EPA 8260B	-	1
Glutaraldehyde in Water by DNPH & LCMSMS*	DNPH derivatisation, extraction, LCMSMS	-	1
Polycyclic Aromatic Hydrocarbons Screening in Water, By Liq/Liq	Liquid / liquid extraction, SPE (if required), GC-MS SIM analysis	-	1
Total Petroleum Hydrocarbons in Water	Hexane extraction, GC-FID analysis US EPA 8015B/MfE Petroleum Industry Guidelines	-	1
Filtration, Unpreserved	Sample filtration through 0.45µm membrane filter.	-	1
Total Digestion	Boiling nitric acid digestion. APHA 3030 E 21st ed. 2005.	-	1
Total Kjeldahl Digestion	Sulphuric acid digestion with copper sulphate catalyst.	-	1
pH	pH meter. APHA 4500-H+ B 21st ed. 2005.	0.1 pH Units	1
Electrical Conductivity (EC)	Conductivity meter, 25°C. APHA 2510 B 21st ed. 2005.	0.1 mS/m	1
Total Dissolved Solids (TDS)	Filtration through GF/C (1.2 µm), gravimetric. APHA 2540 C (modified; drying temperature of 103 - 105°C used rather than 180 ± 2°C) 21st ed. 2005.	10 g/m³	1
Specific Gravity*	Calculation: weight of sample / weight of equivalent volume of water at 20°C. Gravimetric determination.	0.01 20°C/20°C	1

Sample Type: Aqueous			
Test	**Method Description**	**Default Detection Limit**	**Samples**
Hexavalent Chromium	Diphenylcarbazide colorimetry. Discrete Analyser. APHA 3500 Cr B (modified from manual analysis) 21st ed. 2005.	0.010 g/m^3	1
Total Potassium	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 21st ed. 2005.	0.053 g/m^3	1
Total Sodium	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 21st ed. 2005.	0.021 g/m^3	1
Chloride	Filtered sample. Ferric thiocyanate colorimetry. Discrete Analyser. APHA 4500 Cl^- E (modified from continuous flow analysis) 21st ed. 2005.	0.5 g/m^3	1
Total Nitrogen	Calculation: TKN + Nitrate-N + Nitrite-N.	0.05 g/m^3	1
Nitrate-N + Nitrite-N	Total oxidised nitrogen. Automated cadmium reduction, flow injection analyser. APHA 4500-NO_3^- I (Modified) 21st ed. 2005.	0.002 g/m^3	1
Total Kjeldahl Nitrogen (TKN)	Total Kjeldahl digestion, phenol/hypochlorite colorimetry. Discrete Analyser. APHA 4500-N_{org} C. (modified) 4500 NH_3 F (modified) 21st ed. 2005.	0.10 g/m^3	1

These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.

Samples are held at the laboratory after reporting for a length of time depending on the preservation used and the stability of the analytes being tested. Once the storage period is completed the samples are discarded unless otherwise advised by the client.

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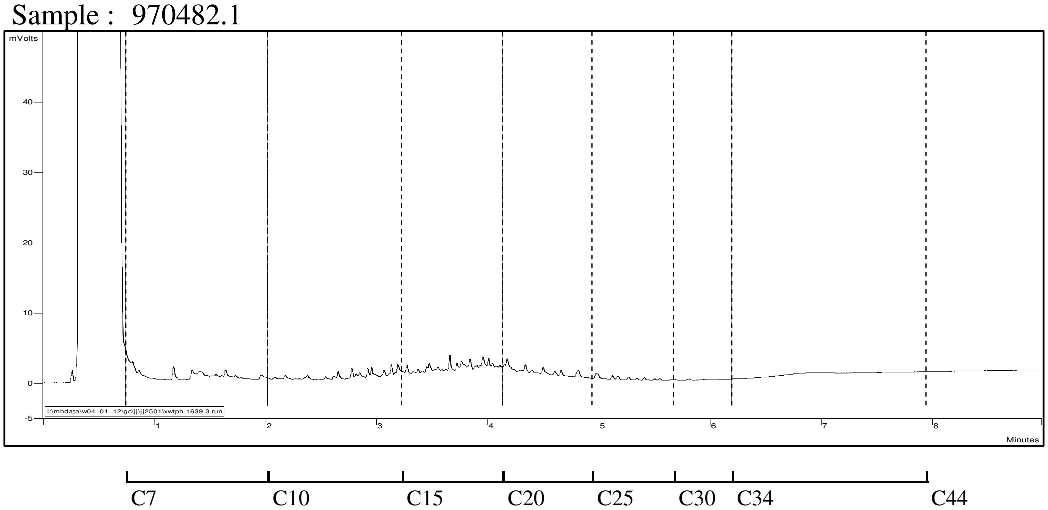
Ara Heron BSc (Tech)
Client Services Manager - Environmental Division

Sample : 970482.1



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ANALYSIS REPORT

SPv4

Client:	BTW Company Ltd	**Lab No:**	947340
Contact:	D Riley	**Date Registered:**	28-Oct-2011
	C/- BTW Company Ltd	**Date Reported:**	08-Nov-2011
	PO Box 551	**Quote No:**	45045
	NEW PLYMOUTH 4340	**Order No:**	
		Client Reference:	Tank Water
		Submitted By:	D Riley

Sample Type: Aqueous

Sample Name:		Man-D WWF 27-Oct-2011 8:30 am				
Lab Number:		947340.1				
Individual Tests						
pH	pH Units	7.1	-	-	-	-
Electrical Conductivity (EC)	mS/m	873	-	-	-	-
Total Dissolved Solids (TDS)	g/m³	5,600	-	-	-	-
Specific Gravity*	20°C/20°C	1.00	-	-	-	-
Hexavalent Chromium	g/m³	0.028	-	-	-	-
Total Potassium	g/m³	1,030	-	-	-	-
Total Sodium	g/m³	1,520	-	-	-	-
Chloride	g/m³	1,970	-	-	-	-
Total Nitrogen	g/m³	64	-	-	-	-
Nitrate-N + Nitrite-N	g/m³	0.017	-	-	-	-
Total Kjeldahl Nitrogen (TKN)	g/m³	64	-	-	-	-
Heavy metals, totals, trace As,Cd,Cr,Cu,Ni,Pb,Zn						
Total Arsenic	g/m³	0.0108	-	-	-	-
Total Cadmium	g/m³	0.00041	-	-	-	-
Total Chromium	g/m³	0.33	-	-	-	-
Total Copper	g/m³	0.048	-	-	-	-
Total Lead	g/m³	0.0069	-	-	-	-
Total Nickel	g/m³	0.036	-	-	-	-
Total Zinc	g/m³	1.30	-	-	-	-
Ethylene Glycol in Water						
Ethylene glycol*	g/m³	< 4	-	-	-	-
Methanol in Water - Aqueous Solvents						
Methanol*	g/m³	290	-	-	-	-
BTEX in Water by Headspace GC-MS						
Benzene	g/m³	2.4	-	-	-	-
Toluene	g/m³	2.7	-	-	-	-
Ethylbenzene	g/m³	0.29	-	-	-	-
m&p-Xylene	g/m³	1.28	-	-	-	-
o-Xylene	g/m³	0.71	-	-	-	-
Glutaraldehyde in Water by DNPH & LCMSMS						
Glutaraldehyde*	g/m³	< 0.03	-	-	-	-
Polycyclic Aromatic Hydrocarbons Trace in Water, By Liq/Liq						
Acenaphthene	g/m³	0.005	-	-	-	-
Acenaphthylene	g/m³	0.003	-	-	-	-
Anthracene	g/m³	< 0.002	-	-	-	-
Benzo[a]anthracene	g/m³	< 0.002	-	-	-	-

Sample Type: Aqueous						
Sample Name:		Man-D WWF 27-Oct-2011 8:30 am				
Lab Number:		947340.1				
Polycyclic Aromatic Hydrocarbons Trace in Water, By Liq/Liq						
Benzo[a]pyrene (BAP)	g/m^3	< 0.002	-	-	-	-
Benzo[b]fluoranthene + Benzo[j] fluoranthene	g/m^3	< 0.002	-	-	-	-
Benzo[g,h,i]perylene	g/m^3	< 0.002	-	-	-	-
Benzo[k]fluoranthene	g/m^3	< 0.002	-	-	-	-
Chrysene	g/m^3	< 0.002	-	-	-	-
Dibenzo[a,h]anthracene	g/m^3	< 0.002	-	-	-	-
Fluoranthene	g/m^3	0.003	-	-	-	-
Fluorene	g/m^3	0.056	-	-	-	-
Indeno(1,2,3-c,d)pyrene	g/m^3	< 0.002	-	-	-	-
Naphthalene	g/m^3	0.44	-	-	-	-
Phenanthrene	g/m^3	0.080	-	-	-	-
Pyrene	g/m^3	0.004	-	-	-	-
Total Petroleum Hydrocarbons in Water						
C7 - C9	g/m^3	12.5	-	-	-	-
C10 - C14	g/m^3	43	-	-	-	-
C15 - C36	g/m^3	63	-	-	-	-
Total hydrocarbons (C7 - C36)	g/m^3	119	-	-	-	-

Analyst's Comments

Appendix No.1 - Total Petroleum Hydrocarbon Chromatograms

SUMMARY OF METHODS

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively clean matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis.

Sample Type: Aqueous

Test	Method Description	Default Detection Limit	Samples
Acetaldehyde and Glutaraldehyde in Water extraction,Trace*	DNPH derivatisation, extraction, HPLC.	-	1
Heavy metals, totals, trace As,Cd,Cr,Cu,Ni,Pb,Zn	Nitric acid digestion, ICP-MS, trace level	-	1
Ethylene Glycol in Water*	Direct injection, dual column GC-FID	-	1
Methanol in Water - Aqueous Solvents*	Direct injection, dual column GC-FID	-	1
BTEX in Water by Headspace GC-MS	Headspace GC-MS analysis, US EPA 8260B	-	1
Glutaraldehyde in Water by DNPH & LCMSMS*	DNPH derivatisation, extraction, LCMSMS	-	1
Polycyclic Aromatic Hydrocarbons Trace in Water, By Liq/Liq	Liquid / liquid extraction, SPE (if required), GC-MS SIM analysis	-	1
Total Petroleum Hydrocarbons in Water	Hexane extraction, GC-FID analysis US EPA 8015B/MfE Petroleum Industry Guidelines	-	1
Filtration, Unpreserved	Sample filtration through 0.45µm membrane filter.	-	1
Total Digestion	Boiling nitric acid digestion. APHA 3030 E 21st ed. 2005.	-	1
Total Kjeldahl Digestion	Sulphuric acid digestion with copper sulphate catalyst.	-	1
pH	pH meter. APHA 4500-H^+ B 21st ed. 2005.	0.1 pH Units	1
Electrical Conductivity (EC)	Conductivity meter, 25°C. APHA 2510 B 21st ed. 2005.	0.1 mS/m	1
Total Dissolved Solids (TDS)	Filtration through GF/C (1.2 µm), gravimetric. APHA 2540 C (modified; drying temperature of 103 - 105°C used rather than 180 ± 2°C) 21st ed. 2005.	10 g/m^3	1
Specific Gravity*	Calculation: weight of sample / weight of equivalent volume of water at 20°C. Gravimetric determination.	0.01 20°C/20°C	1
Hexavalent Chromium	Diphenylcarbazide colorimetry. Discrete Analyser. APHA 3500 Cr B (modified from manual analysis) 21st ed. 2005.	0.0010 g/m^3	1
Total Potassium	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 21st ed. 2005.	0.053 g/m^3	1
Total Sodium	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 21st ed. 2005.	0.021 g/m^3	1

Sample Type: Aqueous			
Test	**Method Description**	**Default Detection Limit**	**Samples**
Chloride	Filtered sample. Ferric thiocyanate colorimetry. Discrete Analyser. APHA 4500 Cl^- E (modified from continuous flow analysis) 21^{st} ed. 2005.	0.5 g/m^3	1
Total Nitrogen	Calculation: TKN + Nitrate-N + Nitrite-N.	0.05 g/m^3	1
Nitrate-N + Nitrite-N	Total oxidised nitrogen. Automated cadmium reduction, flow injection analyser. APHA 4500-NO_3^- I (Proposed) 21^{st} ed. 2005.	0.002 g/m^3	1
Total Kjeldahl Nitrogen (TKN)	Total Kjeldahl digestion, phenol/hypochlorite colorimetry. Discrete Analyser. APHA 4500-N_{org} C. (modified) 4500 NH_3 F (modified) 21^{st} ed. 2005.	0.10 g/m^3	1

These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.

Samples are held at the laboratory after reporting for a length of time depending on the preservation used and the stability of the analytes being tested. Once the storage period is completed the samples are discarded unless otherwise advised by the client.

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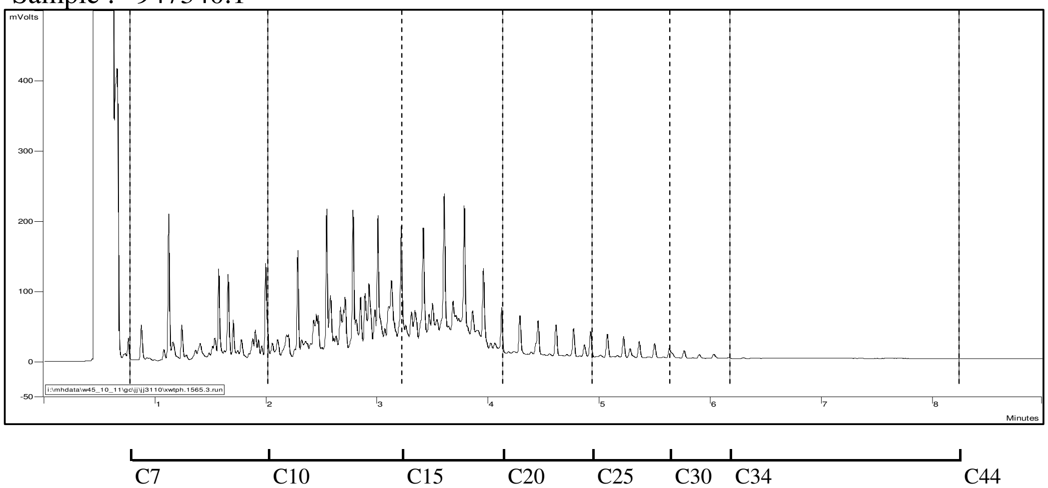
Ara Heron BSc (Tech)
Client Services Manager - Environmental Division

Sample : 947340.1



Appendix G - International examples of regulatory approaches

The need for regulations to deal with hydraulic fracturing is shared in an increasing number of countries around the world. While a small number have opted for moratoria, the vast majority have not. In the few cases where moratoria have been implemented, they have often been lifted following research into the realities of hydraulic fracturing. The overwhelming experience has been that hydraulic fracturing can be regulated to be a safe activity that makes a positive contribution to its host communities.

United States

The United States has the most developed tight gas, shale gas and coal seam gas (CSG) industries, having led the development of these resources.[1] The success of the industries there is motivating other countries to consider their own reserves. Many are looking to the United States for direction in setting their regulations.[2]

In the United States the shift in activities from traditional oil and gas production areas such as Texas, Oklahoma, Louisiana and California to States such as Pennsylvania and New York has prompted fresh debate over the environmental effects and the protections currently in place.[3]

The regulatory framework in the United States is a complex mixture of federal and state laws. Broadly speaking, federal laws focus on maintaining environmental standards, while states are responsible for regulating actual exploration and development activities.[4] The degree of state control is evidenced by the fact that some states have imposed (interim) moratoria on hydraulic fracturing.[5] The rules in place cover the development of tight gas, shale gas and CSG resources, including hydraulic fracturing.

Key federal laws include the Clean Air Act, the Clean Water Act and the Safe Drinking Water Act.

The Clean Air Act sets air quality standards.[6] The Environmental Protection Agency issued new regulations in April 2012 targeted at reducing the amount of gas that escapes and is wasted during production.[7]

The Clean Water Act controls the emission of pollutants into water.[8] The Environmental Protection Agency is investigating establishing hydraulic fracturing specific wastewater disposal standards.[9]

The Safe Drinking Water Act provides for the protection of potable water. The Environmental Protection Agency is charged with setting minimum standards, while states can set higher standards if they choose.[10] The Energy Policy Act 2005 amended the Safe Drinking Water Act to exclude hydraulic fracturing fluids that are not diesel based from its jurisdiction.[11] Instead this aspect of

[1] International Energy Agency, 2012, ‘Golden Rules for a Golden Age of Gas: World Energy Outlook Special Report on Unconventional Gas’, *OECD*. www.worldenergyoutlook.org/media/weowebsite/2012/goldenrules/WEO2012_GoldenRulesReport.pdf

[2] See, for example Energy Resources Conservation Board, January 2011, ‘Unconventional Gas Regulatory Framework – Jurisdictional Review’ (Report 2011-A), *Energy Resources Conservation Board, Alberta*. http://www.ercb.ca/reports/r2011-A.pdf, and

United Kingdom Parliament, 23 May 2011, ‘Annex 1: Note of visit to the USA’, *Shale Gas, House of Commons Energy and Climate Change Committee*. http://www.publications.parliament.uk/pa/cm201012/cmselect/cmenergy/795/79512.htm

[3] See, for example, International Energy Agency, 2012, ‘Golden Rules for a Golden Age of Gas: World Energy Outlook Special Report on Unconventional Gas’, *OECD*. www.worldenergyoutlook.org/media/weowebsite/2012/goldenrules/WEO2012_GoldenRulesReport.pdf, and Banerjee, Neela, 19 February 2012, ‘Fracking debate divides New York landowners’, *Los Angeles Times*. http://articles.latimes.com/2012/feb/19/nation/la-na-fracking-ny-20120219, and

Huffington Post, ‘New York Fracking Debate Focuses On Wastewater’, 21 April 2012, *Huffington Post*. http://www.huffingtonpost.com/2012/02/20/new-york-fracking_n_1288696.html

[4] See, for example, International Energy Agency, 2012, ‘Golden Rules for a Golden Age of Gas: World Energy Outlook Special Report on Unconventional Gas’, *OECD*. www.worldenergyoutlook.org/media/weowebsite/2012/goldenrules/WEO2012_GoldenRulesReport.pdf, and

Energy Institute, February 2012, ‘Fact-Based Regulation for Environmental Protection in Shale Gas Development’, *University of Texas at Austin*. http://energy.utexas.edu/images/ei_shale_gas_regulation120215.pdf

[5] See, for example, Vermont State Legislature, 2012, ‘Bill as Passed the House and Senate’, (signed into law on 5 May 2012), *H.464*. http://www.leg.state.vt.us/docs/2012/bills/Passed/H-464.pdf

[6] US Environmental Protection Agency, 2012, ‘Clean Air Act’. http://www.epa.gov/air/caa/

[7] US Environmental Protection Agency, 2012, ‘Oil and Natural Gas Air Pollution Standards’. http://www.epa.gov/airquality/oilandgas/

[8] US Environmental Protection Agency, 2012, ‘Summary of the Clean Water Act’. http://www.epa.gov/lawsregs/laws/cwa.html

[9] US Environmental Protection Agency, 20 October 2011, ‘EPA Announces Schedule to Develop Natural Gas Wastewater Standards/Announcement is part of administration’s priority to ensure natural gas development continues safely and responsibly’, *Newsroom: News Releases By Date (EPA)*. http://yosemite.epa.gov/opa/admpress.nsf/0/91E7FADB4B114C4A8525792F00542001

[10] US Environmental Protection Agency, 2012, ‘Summary of the Safe Drinking Water Act’. http://www.epa.gov/lawsregs/laws/sdwa.html

[11] Energy Policy Act, 2005, ‘Section 322’. http://www.iogcc.state.ok.us/hydraulic-fracturing

hydraulic fracturing is regulated directly by states. The current arrangement has the express support of the Interstate Oil & Gas Compact Commission, which comprises the governors of most states.[12]

State regulations applicable to the development of tight gas, shale gas and CSG resources are mostly contained within broader oil and gas industry regulations. There has been a trend toward tightening these regulations in response to public debate over the environmental effects of hydraulic fracturing. The attention has focused on well integrity (well casing designs and cementing techniques), disclosure of substances used in the hydraulic fracturing fluids and the treatment and disposal of wastewater.[13]

Some states with little or no history of oil and gas developments recognise the need to strengthen their existing regulations. In some cases, like New York, this has prompted the enactment of bans or temporary bans on hydraulic fracturing pending detailed reviews on the environmental impacts and the adequacy of existing state and federal regulations.[14]

In addition to federal and state laws there are a number of inter-state and industry groups that review and set standards for hydraulic fracturing activities. Two prominent organisations are the State Review of Oil & Natural Gas Environmental Regulations (STRONGER) and the American Petroleum Institute.[15]

Hydraulic fracturing continues to be the subject of investigation and review and further updates of the law are likely.

The Shale Gas Subcommittee of the Secretary of Energy Advisory Board issued the second of two Ninety Day reports in November 2011.[16] These reports stemmed from a directive by President Barack Obama to the Secretary of Energy in March 2011 to look into the safety and environmental performance of shale gas production. Amongst the reports' recommendations are calls to improve public access to information about shale gas operations via dedicated websites, funding for STRONGER and further emission controls.[17]

The Environmental Protection Agency is conducting a comprehensive study into the effects of hydraulic fracturing on water. The study will look at everything from initial water acquisition to disposal and its use between these end points.[18]

Canada

Canada is the world's third largest natural gas producer.[19] It has considerable tight gas, shale gas and CSG resources and is currently active in the development of all three. Tight gas currently makes the largest contribution to total natural gas production, however, shale gas is the largest component of remaining recoverable gas resources and it is expected that investment in shale gas developments will eventually surpass tight gas developments.[20]

The regulatory framework in Canada for tight gas, shale gas and CSG developments is covered by laws and regulations at the local, provincial and federal levels. Resources are owned by, and largely

[12] Interstate Oil & Gas Compact Commission, 2012, 'Member States'. http://www.iogcc.state.ok.us/member-states

[13] International Energy Agency, 2012, 'Golden Rules for a Golden Age of Gas: World Energy Outlook Special Report on Unconventional Gas', *OECD*, p. 104. www.worldenergyoutlook.org/media/weowebsite/2012/goldenrules/WEO2012_GoldenRulesReport.pdf

[14] Paterson, David A, 13 December 2010, 'Executive Order Number 41 of New York Governor David A Paterson: Requiring Further Environmental Review'. http://www.governor.ny.gov/archive/paterson/executiveorders/EO41.html, and

Cuomo, Andrew M, 1 January 2011, 'Executive Order Number 2 of New York Governor Andrew M Cuomo: Review, Continuation and Expiration of Prior Executive Orders'. http://www.governor.ny.gov/executiveorder/2

[15] State Review of Oil & Natural Gas Environmental Regulations, 2012. http://www.strongerinc.org/, and
American Petroleum Institute, 2012, http://www.api.org/

[16] US Department of Energy, 18 November 2011, 'Shale Gas Production Subcommittee Second 90-Day Report', *Secretary of Energy Advisory Board*. http://www.shalegas.energy.gov/resources/111811_final_report.pdf, and

US Department of Energy, 18 August 2011, 'Shale Gas Production Subcommittee 90-Day Report', *Secretary of Energy Advisory Board*. www.shalegas.energy.gov/resources/081811_90_day_report_final.pdf

[17] US Department of Energy, 18 November 2011, 'Shale Gas Production Subcommittee Second 90-Day Report', *Secretary of Energy Advisory Board*. http://www.shalegas.energy.gov/resources/111811_final_report.pdf

[18] US Environmental Protection Agency, 2012, 'EPA's Study of Hydraulic Fracturing and Its Potential Impact on Drinking Water Resources'. http://www.epa.gov/hfstudy/

[19] Canadian Association of Petroleum Producers, 2012, 'What is natural gas?', *Conventional & Unconventional*. http://www.capp.ca/canadaIndustry/naturalGas/Conventional-Unconventional/Pages/default.aspx

[20] International Energy Agency, 2012, 'Golden Rules for a Golden Age of Gas: World Energy Outlook Special Report on Unconventional Gas', *OECD*, p. 108. www.worldenergyoutlook.org/media/weowebsite/2012/goldenrules/WEO2012_GoldenRulesReport.pdf

controlled by, the individual provinces with the exception of native lands.[21] Environment Canada is responsible for the administration and enforcement of federal environmental protection laws. It works with the provincial governments to protect air, water and soil quality (amongst other tasks).[22] The National Energy Board (NEB) is responsible for international and inter-provincial energy issues. In particular, it permits the construction of inter-provincial oil and gas pipelines and oversees the tolls and tariffs applied to such pipelines. It also permits the export of natural gas from Canada, subject to maintaining sufficient supply for the domestic market. Intra-province pipelines are regulated by the provinces.[23]

All provinces have in place laws to protect fresh water aquifers. Regulators have the power to restrict water use. [24]

Industry bodies have also been active in developing guidelines and best practices for hydraulic fracturing. In January 2012, the Canadian Association of Petroleum Producers (CAPP) issued six "Hydraulic Fracturing Operating Practices" which address water management and practices used in the development of tight gas and shale gas resources:[25]

> Hydraulic fracturing fluid additive disclosure.

> Hydraulic fracturing fluid risk assessment and management.

> Baseline groundwater testing.

> Wellbore construction and quality assurance.

> Water sourcing, measurement and reuse.

> Fluid transport, handling, storage and disposal.

The province with the most extensive industry experience is Alberta, where the regulator is the Energy Resources Conservation Board (ERCB). [26] Alongside other standards the ERCB sets minimum surface casing depths for wells, minimum casing cementing standards and well abandonment standards.[27] In 2011, the ERCB published a review of tight gas, shale gas and CSG regulations, as part of its mission "to be the best nonconventional regulator in the world by 2013."[28]

The provinces of Quebec and Nova Scotia have placed a moratoria on the use of hydraulic fracturing.[29]

British Columbia has hydraulic fracturing specific regulations.[30] These regulations also cover factors such as well spacing and flaring limits. The province also requires public disclosure of substances in hydraulic fracturing fluids, including via the www.fracfocus.ca website.[31]

[21] *Ibid*, p. 109.

[22] Environment Canada, 2012, 'About Environment Canada'. http://www.ec.gc.ca/default.asp?lang=En&n=BD3CE17D-1

[23] National Energy Board (Canada), 2012, 'The Construction and Operation of Pipelines and Power Lines'. http://www.neb-one.gc.ca/clf-nsi/rthnb/whwrndrgvrnnc/rrspnsblt-eng.html

[24] See, for example, International Energy Agency, 2012, 'Golden Rules for a Golden Age of Gas: World Energy Outlook Special Report on Unconventional Gas', *OECD*. www.worldenergyoutlook.org/media/weowebsite/2012/goldenrules/WEO2012_GoldenRulesReport.pdf, and

See, for example, Energy Resources Conservation Board, 2011, 'Unconventional Regulatory Framework', *Protecting our Water Resources*. http://www.ercb.ca/about-us/what-we-do/current-projects/urf/protecting-water

[25] Canadian Association of Petroleum Producers, 30 January 2012, 'Industry establishes Canada-wide operating practices for shale, tight natural gas hydraulic fracturing', *New Releases*. http://www.capp.ca/aboutUs/mediaCentre/NewsReleases/Pages/operating-practices-for-hydraulic-fracturing.aspx

[26] Canadian Association of Petroleum Producers, 2012, 'About Us', http://www.ercb.ca/about-us

[27] See Energy Resources Conservation Board, 14 December 2010, 'Surface Casing Depth Requirements', *Directive 008*. http://www.ercb.ca/directives/Directive008.pdf,

Energy Resources Conservation Board, July 1990, 'Directive 009: Casing Cementing Minimum Requirements'. http://www.ercb.ca/directives/Directive009.pdf, and

Energy Resources Conservation Board, 9 June 2010, 'Directive 020: Well Abandonment', *Revised Edition*. http://www.ercb.ca/directives/Directive020.pdf

[28] Energy Resources Conservation Board, January 2011, 'Unconventional Gas Regulatory Framework – Jurisdictional Review' (Report 2011-A), *Energy Resources Conservation Board, Alberta*. http://www.ercb.ca/reports/r2011-A.pdf

[29] Marotte, Bertrand, 9 March 2011, 'Shale gas play a no man's land in Quebec', *The Globe and Mail.* http://www.theglobeandmail.com/globe-investor/shale-gas-play-a-no-mans-land-in-quebec/article572966/, and

Novanite, 4 April 2012, 'Canada's Quebec Bans Shale Gas Hydrofracking Pending Studies', *World.* http://www.novinite.com/view_news.php?id=138217

Nova Scotia, 16 April 2012, 'Province Extends Hydraulic Fracturing Review'. http://novascotia.ca/news/release/?id=20120416004

[30] See, for example clause 21 onwards of B.C. Oil and Gas Commission, 24 September 2010, 'Drilling and Production Regulation', *Oil and Gas Activities Act*, (B.C. Reg. 282/2010). http://www.bclaws.ca/EPLibraries/bclaws_new/document/ID/freeside/282_2010

United Kingdom

In the United Kingdom hydraulic fracturing is largely regulated under wider oil and gas and environmental regulations.[32]

Obtaining permission to conduct hydraulic fracturing requires operators to clear numerous hurdles, including the following. They must obtain a Petroleum Exploration and Development License (PEDL) from the Department of Energy and Climate Change. PEDLs confer an exclusive right to explore for hydrocarbons in a given area. Amongst other things operators must prove technical competence and an awareness of environmental issues before they are granted a PEDL. Planning permission needs to be obtained from the relevant local authorities. The Health and Safety Executive and Environmental Agency must be informed of the planned activities and authorisation must be obtained from the later for the discharge of hydraulic fracturing fluids. As part of this process the content of the hydraulic fracturing fluids must be disclosed to the Environmental Agency. Additional permission to drill needs to be obtained from the Department of Energy and Climate Change.[33]

The Department of Energy and Climate Change has expressed confidence in the adequacy of the regulation of shale gas exploration and development.[34] The House of Commons Energy and Climate Change Committee has stated that it believes a moratorium on hydraulic fracturing is not necessary.[35] The Royal Society and Royal Academy of Engineering affirmed these sentiments in a recent report, but noted that regulations may need to be reviewed to deal with scale effects if the shale gas industry increases in size.[36] They also called for more research into the climate change implications of the extraction and use of shale gas.[37]

Australia

Australia has extensive tight gas, shale gas and CSG resources.[38] Public attention has been focused most intently on CSG. Individual states are largely responsible for the regulation of hydraulic fracturing, however, where matters of national environmental significance are affected consideration also needs to be had to commonwealth legislation.[39] Victoria currently has a moratorium on hydraulic fracturing.[40]

State and Commonwealth energy and resources ministers are in the process of developing a national harmonised regulatory framework for the CSG industry, via the Standing Council on Energy and Resources. Part of this work covers hydraulic fracturing. The framework is expected to be complete by December 2012.[41]

[31] British Columbia Online News Source, 9 January 2012, ‘Canada’s first hydraulic fracturing registry now online’. http://www.newsroom.gov.bc.ca/2012/01/canadas-first-hydraulic-fracturing-registry-now-online.html

[32] The Royal Society and The Royal Academy of Engineering, June 2012, ‘Shale gas extraction in the UK: a review of hydraulic fracturing’, *United Kingdom*, p. 53. http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/projects/shale-gas/2012-06-28-Shale-gas.pdf, and

Department of Energy and Climate Change (UK), 2012, ‘Shale Gas’, *Oil and gas*. http://www.decc.gov.uk/en/content/cms/meeting_energy/oil_gas/shale_gas/shale_gas.aspx

For an overview of all legislation applicable to onshore hydrocarbon exploitation in the United Kingdom see: Department of Energy and Climate Change (UK), 25 July 2011, ‘Environmental legislation applicable to onshore hydrocarbon industry’. http://og.decc.gov.uk/assets/og/environment/onshore_leg(1).doc

[33] The Royal Society and The Royal Academy of Engineering, June 2012, ‘Shale gas extraction in the UK: a review of hydraulic fracturing’, *United Kingdom,* pp. 53-55. http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/projects/shale-gas/2012-06-28-Shale-gas.pdf

[34] Department of Energy and Climate Change (UK), 2012, ‘Shale Gas’, *Oil and gas*. http://www.decc.gov.uk/en/content/cms/meeting_energy/oil_gas/shale_gas/shale_gas.aspx

[35] Energy and Climate Change Committee, May 2011, ‘Fifth Report Shale Gas’, House of Commons, (Parliamentary Business/Publications and Records). Paragraph 17 http://www.publications.parliament.uk/pa/cm201012/cmselect/cmenergy/795/79505.htm#a4

[36] The Royal Society and The Royal Academy of Engineering, June 2012, ‘Shale gas extraction in the UK: a review of hydraulic fracturing’, *United Kingdom,* p. 55. http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/projects/shale-gas/2012-06-28-Shale-gas.pdf

[37] *Ibid*, pp. 57-58.

[38] International Energy Agency, 2012, ‘Golden Rules for a Golden Age of Gas: World Energy Outlook Special Report on Unconventional Gas’, *OECD*, p. 130. www.worldenergyoutlook.org/media/weowebsite/2012/goldenrules/WEO2012_GoldenRulesReport.pdf

[39] Department of Manufacturing, Innovation, Trade, Resources and Energy, May 2012, ‘First Draft Roadmap for Unconventional Gas Projects in South Australia’, *Government of South Australia*, p. 134. http://www.misa.net.au/__data/assets/pdf_file/0004/171616/DRAFT_ROADMAP_11_May_2012_final.pdf

[40] Premier of Victoria, 24 August 2012, ‘Reforms to strengthen Victoria’s coal seam gas regulation and protect communities’, *Media Releases*. http://www.premier.vic.gov.au/media-centre/media-releases/4710-reforms-to-strengthen-victorias-coal-seam-gas-regulation-and-protect-communities-.html

[41] Standing Council on Energy and Reseources, 2012, ‘Coal Seam Gas’, *Work Streams: Land Access.* http://www.scer.gov.au/workstreams/land-access/coal-seam-gas/

Two issues that feature prominently in the wider Australian natural gas debate are water drawdown and land access. Neither issue is specifically related to hydraulic fracturing, so are only mentioned here briefly. Water drawdown refers to the need to draw water out of coal seams when producing CSG, to allow the gas held in place by the water pressure to be extracted. There have been suggestions that this is affecting water levels, including in the Great Artesian Basin. Land access relates to the legal framework via which oil and gas firms obtain access to land for exploration and production activities. This has been criticised by some landowners.

Specific hydraulic fracturing regulations in South Australia, Queensland and Victoria are profiled in further detail below.

South Australia

Over 700 wells have been hydraulically fractured in South Australia since 1969.[42] The state regulates upstream hydrocarbon activities via its Petroleum and Geothermal Energy Act 2000. Operators are required to obtain various licences to operate, including petroleum exploration, retention and production licences.[43] Before carrying out work, operators need to complete an Environmental Impact Report that identifies risks associated with their activities and strategies for managing these. This culminates in a Statement of Environmental Objectives. This sets out objectives relating to the management of the risks and criteria to help determine whether these objectives have been met.[44]

Queensland

Queensland has considerable proven CSG resources, and potential for tight gas and shale gas production.[45] CSG makes up the majority of all natural gas production in Queensland.[46] Exploration and production activities are regulated by the Petroleum Act 1923, the Petroleum, Gas (Production and Safety) Act 2004 and the Mineral Resources Act 1989.[47] The state requires CSG projects to obtain an environmental authority (EA) to operate. These authorities set out conditions to manage environmental impacts. Large scale projects are subject to an environmental impact statement (EIS) process before they are eligible for an EA. The EIS involves identifying potential impacts on the environment, and strategies for managing these.[48] Baseline assessments of water quality are required before hydraulic fracturing takes place.[49] Government and landowners are notified before and after hydraulic fracturing, including being given information about planned and actual chemical use and volume.[50]

The use of BTEX chemicals (benzene, toluene, ethylbenzene and xylene) in hydraulic fracturing is heavily restricted. They cannot be used as additives in hydraulic fracturing fluid, however, some allowance exists for trace amounts to be present during hydraulic fracturing due to their occurrence in water sources and use in machinery products (such as petrol).[51]

[42] Department of Manufacturing, Innovation, Trade, Resources and Energy, May 2012, 'First Draft Roadmap for Unconventional Gas Projects in South Australia', *Government of South Australia*, p. 212. http://www.misa.net.au/__data/assets/pdf_file/0004/171616/DRAFT_ROADMAP_11_May_2012_final.pdf

[43] Department for Manufacturing, Innovation, Trade, Resources and Energy (Government of South Australia), January 2012, 'Types of Licences', *DMITRE Petroleum*. http://www.pir.sa.gov.au/petroleum/licensing/licence_types

[44] Government of South Australia, 2012, 'DMITRE Petroleum', *Frequently Asked Questions*. http://www.petroleum.dmitre.sa.gov.au/prospectivity/basin_and_province_information/unconventional_gas/frequently_asked_questions

[45] Queensland Government, Department of Employment, Economic Development and Innovation, January 2012, 'Queensland's unconventional petroleum potential: Shale gas, tight gas and coal seam gas', *Geological Survey of Queensland*. http://mines.industry.qld.gov.au/assets/petroleum-pdf/cc12-pet007_q_unconvent.pdf

[46] Queensland Government, 2012, 'Queensland's gas reserves', *Gas industry: Gas in Queensland*. http://www.business.qld.gov.au/industry/energy/gas/gas-queensland/queenslands-gas-reserves

[47] Queensland Government, 2012, 'Coal seam gas', *Mining and safety*. http://mines.industry.qld.gov.au/mining/coal-seam-gas.htm

[48] Queensland Government, 2012, 'Projects and approvals conditions', *Regulatory framework for CSG-LNG industry*. http://www.business.qld.gov.au/industry/csg-lng-industry/regulatory-framework-csg-lng/project-approvals-conditions

[49] Queensland Government, Department of Environment and Heritage Protection, 2012, 'Regulating Fraccing'. http://www.ehp.qld.gov.au/management/coal-seam-gas/regulating-fraccing.html

[50] *Ibid.*

[51] Queensland Government, 2012, 'CSG-LNG legislation'. http://www.business.qld.gov.au/industry/csg-lng-industry/regulatory-framework-csg-lng/csg-lng-legislation

Victoria

Victoria has placed a hold on approvals to undertake hydraulic fracturing as part of onshore gas exploration and on the issuing of new CSG exploration licences, until it has considered the national harmonised regulatory framework for CSG and amended its legislation accordingly. Hydraulic fracturing has been conducted safely in Victoria in the past. The state is in the early stages of developing its CSG resources. The state prohibits the use of BTEX chemicals in hydraulic fracturing.[52]

[52] Premier of Victoria, 24 August 2012, 'Reforms to strengthen Victoria's coal seam gas regulation and protect communities', *Media Releases*. http://www.premier.vic.gov.au/media-centre/media-releases/4710-reforms-to-strengthen-victorias-coal-seam-gas-regulation-and-protect-communities-.html

Hydraulic Fracturing Operations Conducted by Todd Energy – A Comparison with International Examples and Best Practice

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1. Todd Energy's Hydraulic Fracturing Operations – Comparison to US Shale Gas Operations

International experience has raised public concern over hydraulic fracturing. It is however important to ensure any discussion of hydraulic fracturing in New Zealand clearly portrays both differences and similarities between operations conducted locally and those conducted overseas.

Todd Energy has performed 12 fracture treatments in the past 15 years predominantly within the Mangahewa field. Five wells were treated. Todd Energy is also a 50% partner in the Kapuni field where Shell Todd Oil Services have undertaken 14 fracture treatments (since 1993).

The fracturing operations conducted by Todd Energy are typically separated by 2,500m of impermeable sediments from the base of freshwater aquifers (Todd Energy submission, 2012). By comparison shale gas fracturing in the Barnett Shale (USA) are separated from freshwater aquifers by a minimum of 850m (2,800ft) and typically 1,450m (4,800 ft) (King, 2012). The fractures created by Todd Energy are clearly much further below the base of freshwater zones than fractures created in major shale gas plays in the US. Todd Energy's fracturing operations typically occur at depths of 3,290m below sea level (Todd Energy submission, 2012) where as US operations are generally shallower with depths of 1,423m (Barnett shale) to 3,936m (Eagle Ford shale) (King, 2012).

Another key difference between the fracturing operations conducted by Todd Energy are that US shale gas fracturing operations normally use large volumes of water, e.g. 11,350 m^3 in Niobara shale examples to 21,200 m^3 in the Marcellus shale (3 million to 5.6 million gallons) (King, 2012). By contrast the average volume of Todd's fracture treatments is only 240 m^3. This is approximately 2% of the volume used in the smaller US shale gas fracturing examples.

A further key difference is the medium which is targeted. Shales are more ductile and require a higher pressure (at similar depth) to fracture, than the sandstones targeted by Todd Energy. Furthermore, as sandstones are more brittle than shales, fractures preferentially grow in sandstones and fracture growth is contained by shale layers (unless there are only shales in the vicinity of the fracture (as is the case in shale fracturing)). In other words fractures take the road of the least resistance. As a result the risk of uncontrolled upwards growth is far smaller when fracturing sandstones.

The next section discusses the track record of the larger volume fracture treatments, conducted at shallower depths in the United States.

2. Track Record of Hydraulic Fracture Operations in US

New Zealand has a very modest number of oil and gas wells when compared to most international hydrocarbon producing nations. Kell (2011) provides statistics that document risk of pollution from the operation of oil and gas wells in the context of production from large numbers of wells. The data in Kell (2011) make it clear that documented pollution incidents from oil/gas well drilling and production are rare. The study reports that:

- Over a 26 year time period in Ohio 65,000 wells were producing. In that timeframe 185 pollution cases were investigated by "at state level with investigators knowledgeable about local geology and operations" (quote SPE 152596). 74 of these incidents were drilling and completion related, 39 production related, 41 orphan well related, 26 were water disposal related and five were plugging and abandoning related. **No fracturing related pollution incidents were documented.**
- Similar findings were reported in the Kell (2011) study for Texas which has 250,000 wells producing over a 16 year study period. 211 pollution incidents were documented: 10 drilling and completion, 56 production, 30 orphan well related, 75 waste disposal, one plugging and abandoning and 39 unknown. **No pollution incidents were attributed to fracturing.**

Note that a later part of the study investigated 16,000 multi-fractured horizontal wells. No evidence of groundwater contamination was found in any stage of drilling, well construction, fracturing or operation of these wells. No wells of this type have been completed in New Zealand.

Shale gas production in some states, such as Pennsylvania, have received considerable attention because of concerns that hydraulic fracturing has lead to natural gas contaminating water wells. A study by researchers from Duke University (Osborn, 2011) based on sixty samples reported elevated methane levels in water wells in areas where hydraulic fracturing had been performed. This study did not have baseline data on the water quality in these wells before fracturing took place. A wider study from 2010 onwards sampled all wells within 750m (2,500 ft) of proposed gas well drilling sites (Molofsky, 2011). "Cabot Oil & Gas also collected an extensive background set of water samples in an 80 sq mile area in Brooklyn, Harford and Gibson townships in 2011 for analyses of dissolved gases". This resulted in a data-set of 1,713 measurements. Molofsky notes that 78% of the water wells in this data set have detectable methane concentrations. Analysis of the data showed statistically significant correlation with local topography with higher methane concentrations in water wells located in valleys. Molofosky reports that the US Geological Survey found a similar conclusion for wells in West Virginia in a data set of 170 wells sampled in 1997 to 2005. In Susquehanna County 303 shale gas wells were drilled from July 2006 to September 2011. Analysis of water sampled in the wells through 2011 showed no statistically significant correlation between dissolved methane concentration and whether the wells were within 1km of gas wells drilled prior to 2011, or the wells were in non-producing areas. Historical records of shallow water wells drilled in Pennsylvania from the 1930s onwards document the presence of natural gas in some wells. Molofsky discusses the local geology of the region and explains that there are shallow formations which are naturally charged with thermogenic methane (methane formed from thermal decomposition of buried organic material (swamp gas)) at depths which would be accessed by local water wells. This is supported by detailed isotopic analysis of the methane found in their dataset of samples from wells. The UK Royal Society of Science and Engineering's 2012 report into hydraulic fracturing supports this explanation of the presence of methane in water wells. Other scientists (e.g Davies (2011), Saba and Orzechowski (2011)) have critically reviewed the Duke University study, e.g. Davies (2011) states that:

> "The water well dataset is small, non-random and covers a geologically diverse area that is up to ~200km wide. Several of the contaminated water wells come from around Dimock in Pennsylvania. At Dimock in 2009 and 2010, it was reported that aquifer contamination was caused by recent casing leaks in at least three wells rather than hydraulic fracturing".

Recommendation #1: *Baseline water quality monitoring is important around in any area where oil/gas wells are to be drilled, produced and potentially hydraulically fractured. It is important that an environmental baseline is established before the wells are drilled (or fractured) to clearly delineate whether there are cause and effect relationships between well operations and water quality.*

There are scenarios where the presence of methane in groundwater cannot be explained by local geological features and effects. The importance of appropriate well construction and well integrity is documented in the next section since this is critical to ensuring that wells (hydraulically fractured or otherwise) do not provide man-made pathways for hydrocarbons, drilling fluids or fracturing fluids to contaminate shallower zones containing potable water or other resources.

3. Well Construction

Appropriate well construction and integrity is of upmost importance with regards to the protection of aquifers. The UK Royal Society of Science and Royal Academy of Engineering (2012) report notes that it is best practice to cement casings all the way back to surface, depending on local geology and hydrogeology conditions. In local fracturing operations conducted by Todd Energy freshwater is found to depths of 275m (below ground level) while surface casing is run to approximately 800m and cemented back to surface. This provides a barrier between shallow water bearing zones and fluids injected into, or produced from the wellbore. Further strings of casing (and cement) provide this isolation to deeper zones.

Wells near the Pavillion area of Wyoming are a notable example of where hydraulic fracturing practices have occurred which are very different to operations by Todd Energy in Taranaki. A report by the US EPA (2011) documents that wells in this area have surface casing that is as shallow as 110m, groundwater is produced from depths as deep as 244m, and that fracturing has occurred at depths as shallow as 372m. Note that Todd's operations are typically at depths of 3,400-4,400m with surface casing to 800m (and further cemented casing strings beyond that depth) and freshwater at 275m. The vertical separation between the interval being targeted for fracturing and the freshwater zone is clearly significantly different in the Pavillion and Todd Energy cases.

A further cause for concern in the Pavillion wells is the EPA report's discussion of well completions. Cementing casing thoroughly is crucially to isolating zones from one and other. However at Pavillion there are multiple documented incidences of "no cement or sporadic bonding outside production casing" (US EPA, 2011). This means that the wellbores in this area acted as pathways via which methane could migrate from the fractured zones into freshwater bearing zones.

The quality of the cement that is place between the rock formations and the casing strings can be assessed by cement bond logs. Wells can also be pressure tested to ensure their integrity. Cement bond logs at Pavillion showed poor cement quality at pre-hydraulic fracturing conditions, however the fracturing operations proceeded regardless. This is in violation of accepted best practice standards.

Recommendation #2: *All well construction and fracturing operations in New Zealand must follow relevant international standards such as the American Petroleum Institute HF1, H2 and HF3 standards.*

Note that Todd Energy already complies with these standards - and an extensive list of other standards listed in their submission.

4. Todd Energy's Fracturing Operations – Comparison to International Best Practice Recommendations

Various international agencies are reviewing or have reviewed hydraulic fracturing. This includes work being done by the US Environmental Protection Agency and a recent report by the UK's Royal Society for Science and Engineering. The latter made ten recommendations in June 2012. Table 1 discusses Todd Energy's current fracturing practices in the context of those recommendations. Only those recommendations relevant to actions by operating companies (as opposed to be regulators or other agencies) are considered in this section.

Table 1 – Comparison of Todd Energy practices to best practice recommendations from UK Royal Society of Science and Engineering report (2012).

Topic	Quoted Recommendation from UK Royal Society	Todd Energy's practice
Groundwater Contamination	"Operators should carry out site-specific monitoring of methane and other contaminants in groundwater before, during and after shale gas operations."	The Taranaki Regional Council undertakes, at Todd's expense, the monitoring of farm and domestic bores within a 2.5 km radius of wellsites. Todd Energy recently installed shallow piezometer bores in the immediate vicinity of a flare pit (C site), analysing samples for hydrocarbons, chlorides, etc. No contamination above detectable limits was measured.
Well Integrity	"Operators should ensure that well integrity tests are carried out as appropriate, such as pressure tests and cement bond logs."	Todd Energy follows a comprehensive list of industry standards and guidelines detailed in section 2.5 of their survey response to the PCE. These include the American Petroleum Institute's HF1, HF2 and HF3 documents.
Seismicity	"Seismicity should be monitored before, during and after hydraulic fracturing." "Traffic light monitoring systems should be implemented and data fed back to well injection operations so that action can be taken to mitigate any induced seismicity."	Micro-seismic monitoring is not practical due to well spacing and presence of seismic energy absorbing coals. Todd Energy has not yet used tiltmeters due to the depth of its fracturing operations, the land disturbance related to the installation of a tiltmeter grid, and costs. However, it monitors developments, and will reassess the use of tiltmeters in case it wishes to pursue fracturing closer to surface.
Gas Leakage	"Operators should monitor potential leakages of methane or other emissions to the atmosphere before, during and after shale gas operations."	As discussed in Todd Energy's survey response air emissions are generally not monitored on individual wellsites due to the minor nature of air discharges and the practical difficulties of sampling the high energy discharges associated with intermittent flaring.
Water Use	"Techniques and operational practices should be implemented to minimise water use and avoid abstracting water from supplies that may be under stress." "Options for treating and disposing of wastes should be	Todd Energy's use of water for fracturing operations is at much lower volumes than international shale gas examples and does not come from stressed water supplies.

	planned from the outset. The construction, regulation and siting of any future onshore disposal wells need further investigation."	Todd Energy has consents for waste disposal via land farming and deep well injection. Details of these operations can be found in section 6.4 of the Todd Energy submission. Both methods are considered to be appropriate.
Environment Risk	"An Environmental Risk Assessment (ERA) should be mandatory for all shale gas operations, involving the participation of local communities at the earliest possible opportunity. The ERA should assess risks across the entire lifecycle of shale gas extraction, including the disposal of wastes and well abandonment. Seismic risks should also feature as part of the ERA."	Todd Energy's risk management processes address all aspects of well construction and hydraulic fracturing. The company has a strong commitment to environmental stewardship and to working with the local community.
Risk Management	"Operators should carry out goal based risk assessments according to the principle of reducing risks to As Low As Reasonably Practicable (ALARP). The UK's health and safety regulators and environmental regulators should work together to develop guidelines specific to shale gas extraction to help operators do so. Operators should ensure mechanisms are put in place to audit their risk management processes."	See above.

5. Concluding Remarks

The UK Royal Society report (2012) found that "the health, safety and environmental risks associated with hydraulic fracturing can be effectively managed through the implementation and enforcement of operational best practices." The fracturing operations conducted by Todd Energy to date in New Zealand have been reviewed and have been shown to be much smaller in scale (i.e. smaller volumes of fluid injected) than key international examples. Todd Energy are performing fracturing operations which are typically vertically separated by 2,500m or more from groundwater resources – as opposed to international examples in which fracturing has occurred in much closer proximity to water resources. No evidence of air or water contamination from Todd Energy's operations has been documented. Internationally the track record of hydraulic fracturing shows that very large numbers of wells have been fractured in the United States without incident when best practices are followed. Todd Energy's operations follow all relevant international standards regarding well construction and hydraulic fracturing. The author believes that continued hydraulic fracturing operations by Todd Energy (if practiced in a similar manner to their current operations) do not pose health, safety or environment risks that are in any way unacceptable or inappropriate.

6. Biography - Associate Professor Rosalind Archer

Rosalind Archer holds a B.E. degree in Engineering Science from the University of Auckland. She holds Masters and PhD degrees in Petroleum Engineering. She was employed for 2.5 years as an Assistant Professor in the Petroleum Engineering Dept of Texas A&M University before joining the University of Auckland in 2002. At the University of Auckland she is an Associate Professor, a Deputy Head of the Dept of Engineering Science, and the Faculty of Engineering theme leader for energy research. She undertakes independent consultancy activities via her consulting company (Capricorn Solutions Ltd). Her client list includes Austral Pacific, Greymouth, Genesis, Todd Energy, Shell Todd Oil Services, and multiple international clients (training courses through NExT and Petroskills). Rosalind Archer's research at the University of Auckland is not financially supported by any petroleum company operating in New Zealand.

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HYDRAULIC FRACTURING OPERATIONS CONDUCTED BY TODD ENERGY – AN INDEPENDENT COMMENTARY

Professor Richard Selley

This submission is comprehensive, authoritative, well researched and well documented by a company with extensive experience of hydraulic fracturing. In New Zealand a government regulatory framework for oil/gas field operations in general and hydraulic fracturing in particular has long been in place and appears to be effective.

Good practice includes early and ongoing engagement with the local population with total transparency of what is planned. Baseline monitoring of soil, soil fluids and atmosphere, together with detailed (preferably 3D) seismic surveying of a proposed well location are all essential. The Todd Energy submission addresses all these issues.

Contrary to reports in the media there is nothing new in shale gas, hydraulic fracturing and horizontal drilling.

- Shale gas has been produced in the USA since 1821.
- Hydraulic fracturing has been going on since the nineteen-forties.
- Horizontal drilling developed over 20 years.
- New Zealand, like most developed countries, has a robust and effective regulatory framework already in place.
- The importance of security of gas supply in a troubled world is self evident.
- Methane escapes into the atmosphere whenever gas is transported over long distances by pipeline or tanker. It is better to produce indigenous gas with small transport distance & cost.

Opposition to ‘fraccing’ and shale gas production has been driven by activists concerned that shale gas production may inhibit the establishment of a ‘low carbon’ economy and thus increase global warming. This is a legitimate concern, but the opposition is based on emotion rather than evidence. Many of the ‘facts’ are downright wrong.

After the tremors set off by Cuadrilla’s fraccing of the Preese Hall well in the UK the local newspaper published a photograph of cracks in a near by road. These cracks had been reported to the local council long before Cuadrilla started drilling. Many of the cited ‘experts’ are nothing of the kind (See the attached local newspaper article about how fraccing will trigger volcanic eruptions by an ‘expert’ without the academic or professional qualifications that would allow them to comment authoritatively on the matter.). The ‘documentary’ GASLAND has had a global impact. It is now totally discredited. The celebrated film clip of a man setting fire to a water tap makes great television. This was checked out by the Colorado Oil & Gas Commission before the film was made, and by the US Environment Protection Agency after the film was made. Both studies showed that the gas was marsh gas, biogenic methane. It had absolutely nothing to do with hydraulic fracturing. Sadly a talking head rebutting the film is not as dramatic as the actual clip.

I recently attended a conference on shale gas with papers presented by UK shale gas operators, government organisation, and academics. There was remarkable unanimity that since no shale gas has yet been produced in the UK, it is impossible to establish how much shale gas may be in place and actually produced. It would, however, be an irresponsible government that did not encourage the exploration for shale gas.

The key issues for managing hydraulic fracturing operations are:

1. Well integrity
2. Groundwater protection
3. Chemical transparency
4. Seismicity
5. Flow back fluid treatment and disposal
6. Gas emissions
7. Review & verification of regulations

Many studies have now been published identifying the risks and showing how the risks of hydraulic fracturing can be mitigated. For example:

- the UK's Royal Society/Royal Academy of Engineering report.
- the report produced for the UK's Department of Energy & Climate Change by Green et al 'Preese Hall Shale Gas Fracturing Review and Recommendations for Induced Seismic Mitigation'. April 2012.
- Energy Institute of the University of Texas, Austin. 'Fact-Based Regulation for Environmental protection in Shale Gas Development'. February 2012. http://energy.utexas.edu/.
- Den Norsk Veritas has a consultation document out for insurance regulation purposes www.dnv.com Press release 25th September 2012.

Dick Selley
Professor R C Selley
Chartered Geologist
1 October 2012

'We could be sitting on a Mendip volcano' says Somerset expert

Saturday, December 03, 2011

Wells Journal

Does a great and terrible fate await us if drilling starts below the Mendip hills to extract gas?

A Mendip hills expert says it might. Nigel Taylor, caver, wildlife and nature campaigner, explosives expert and Mendip district councillor, has carried out a study of the Mendip Hills and has discovered that there is a volcanic plug that could be holding back a river of lava ready to erupt if disturbed.

"It may sound ridiculous," said Mr Taylor, "but it is no more ridiculous than drilling deep into the earth's crust and setting off explosions to release trapped gas without knowing all of the potential consequences.

"We could be sitting on a Mendip volcano."

Mr Taylor says that Moons Hill Quarry, which is situated at the heart of the Mendip Plateau near Stoke St Michael, is a massive Silurian Volcanic plug of Basalt rock.

He said: "The rain falling onto the Mendips soaks down, and are superheated on their journey to the Roman Baths at Bath by volcanic activity deep in the earth's surface under that volcanic plug, long thought extinct."

"But what could happen if the exploration company is allowed to carry out 'Fracking activities' on the Mendips?"

Fracking is the process of pumping water underground until the gas bearing shale fractures and releases the pressurised gas it contains.

In the United States fracking has been blamed for widespread pollution – with its release in the water supply causing tap water to catch fire.

The energy industry says the process is safe and an essential source of energy for the future.

Mr Taylor said: "I am keeping an open mind about all of this, but have more than a pressing concern about a risk that nobody appears to have either realised or considered.

"We could either end up diverting the hot waters from Bath into ruptured rocks deep below us, pollute them with shale oils and gases, or the doomsday nightmare scenario – destabilise our geology and awake a sleeping giant."

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Glossary

Term	Definition
Additives	A product composed of one or more chemical constituents that is added to a primary carrier fluid to modify its properties in order to form hydraulic fracturing fluid,
Annulus	The space between the wellbore and casing or between casing and tubing, where fluid can flow. Also known as annular space.
Aquifer	A geological unit containing sufficient saturated permeable rock to yield significant amounts of water.
Bbl	Barrel. A volumetric unit of measurement equivalent to 0.159m^3
Bunding	A secondary enclosure to contain leaks and spills.
Cap rock	A layer of relatively impermeable rock overlying an oil- or gas-bearing rock. Also known as a seal.
Casing	Metal pipe inserted into a wellbore and cemented in place to protect both subsurface formations and the wellbore.
Coal seam gas	Naturally occurring gas trapped in underground coal seams by water and ground pressure. Also known as coal bed methane.
Conventional oil and gas	Oil and gas found in sandstone or carbonate reservoirs which are not the source rocks, and which can normally be exploited without the need for stimulation.
Deep well injection	Injecting waste fluids into a deep well, sometimes a depleted oil or gas well, for safe disposal below the ground.
Displacement fluid	The fluid, usually drilling mud, used to force cement slurry out of the casing string and into the annulus.
Drilling fluid	Mud, water, or air pumped down the drill string which acts as a lubricant for the bit and is used to carry rock cuttings back ip the wellbore. It is also used for pressure control in the wellbore.
Flare	The burning of unwanted gas through a pipe (also called a flare).
Flowback	The process of allowing fluids to flow from the well following a treatment, either in preparation for a subsequent phase of treatment or in preparation for clean-up and returning the well to production.
Flowback water	The fluid that flows back to the surface following a fracturing treatment. It is a mixture of the original fracturing fluid and saline water containing dissolved minerals from the target formation.
Formation	A body of rock that is sufficiently distinctive and continuous that it can be mapped. Formations may be combined into groups or subdivided into members.
Freshwater interface	Surface separating a body of fresh water and one of saltwater, taken somewhere within the transition zone between the two fluids.
Gel breaking	An additive used in hydraulic fracture fluid to reduce the viscosity of a fluid (break it down) after the thickened fluid has finished the job it was designed for.
Gelling agent	An additive in the hydraulic fracture fluid to thicken the water to suspend the proppant.

Guar Gum	A natural thickener made from the beans of the guar plant. Used in hydraulic fracturing fluids to thicken the water to suspend the proppant.
Horizontal drilling	Deviation of the borehole from vertical so that the borehole penetrates a productive formation with horizontally aligned strata, and runs approximately horizontally.
Hydraulic fracturing	A means of increasing the flow of oil or gas from a rock formation by pumping proppant-laden fluid at high pressure into the well, causing fractures to open in the formation. The fractures provide a large surface area through which hydrocarbons are produced and a conductive channel (the fracture) which facilitates flow of the hydrocarbons back to the well.
Hydrostatic pressure	The normal, predicted pressure for a given depth or the pressure exerted per unit area by a column of freshwater from sea level to a given depth.
Land farming	Bioremediation treatment process that is performed in the upper soil zone to breakdown hydrocarbon wastes.
Limestone	A sedimentary rock consisting chiefly of calcium carbonate.
Lithology	The macroscopic nature of the mineral content, grain size, texture and colour of rocks.
Matrix	The groundmass of fine-grained material separating clasts in a sedimentary rock.
Micro-seismic	Very small seismic events, normally below -1.5 ML.
mD	MilliDarcy. A unit of measure used for quantifying permeability in the petroleum industry (see Permeability below).
Natural gas	The gaseous constituents of petroleum .ie. methane, ethane and propane.
Overburden pressure	The pressure or stress imposed on a layer of rock by the weight of overlying material. Also known as lithostatic pressure or vertical stress.
Petroleum	All naturally occurring hydrocarbon.
Permeability	A measure of the ability of a rock to transmit fluid through pore spaces.
Porosity	A ratio between the volume of the pore space in reservoir rock and the total bulk volume of the rock. The pore space determines the amount of space available for fluids.
Portland cement	The most common type of cement used for oil- and gas-well cementing. The cement is obtained by pulverising clinker consisting essentially of hydraulic calcium silicates.
Produced water	The fluid that returns to the surface during the production phase of a well that may contain both fracturing fluid and saline water from the reservoir.
Proppant	Particles (often sand) added to fracturing fluid to hold fractures open after hydraulic fracturing.
Reservoir	A subsurface body of rock that acts as a store for hydrocarbons.
Sandstone	A sedimentary rock composed chiefly of sand-like quartz grains cements by lime, silica or other materials.
Sedimentary	One of the three main classes of rock. Sedimentary rocks are formed at the Earth's surface through deposition of sediments derived from weathered rocks, biogenic activity or precipitation from solution.
Seismicity	Sudden geological phenomena that release energy in the form of vibrations that

	travel through the earth as compression (primary) or shear (secondary) waves.
Shale	A fine-grained, fissile, detrital sedimentary rock formed by the consolidation of clay- and silt-sized particles into thin, relatively impermeable layers.
Shale gas	Natural gas produced from shale formations.
Tight gas	Gas produced from a relatively impermeable reservoir rock. It can be extracted by fracturing the rock typically using vertical wells and less fracturing fluid.
Tiltmeter	An instrument used to detect micro-deformations in surrounding rock.
Unconventional gas	Gas contained in rocks of low gas permeability which require stimulation to be economically recoverable, and which have traditionally been too difficult or costly to produce.
VOC	Volatile Organic Compound.
Well integrity	The ability of the well to prevent hydrocarbons or operational fluids leaking into the surrounding environment.

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