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29 May 2014

Dr Allan Hawke AC
Commissioner
Northern Territory Inquiry into Hydraulic Fracturing
c/- GPO Box 4204, Darwin NT 0801

By email: hydraulicfracturing.inquiry@nt.gov.au

Dear Commissioner

Halliburton is pleased to have the opportunity to make a submission to the inquiry you are conducting on behalf of the Government into hydraulic fracturing for hydrocarbon deposits in the Northern Territory.

Halliburton is a member of the Australian Petroleum Production and Exploration Association (APPEA) and has had the opportunity to view its submission to the inquiry. We are generally in agreement with the views set out in the APPEA submission and have therefore sought to focus the comments in the attached response on areas where Halliburton has additional thoughts or expertise to contribute.

Halliburton is willing to provide further information to the Inquiry as required. We would also like to extend an invitation to you to visit Halliburton's Australian facilities in Perth as well as the company's global technology centre in the United States, should an appropriate opportunity arise.

Please don't hesitate to contact me should you require any further information regarding this submission or any other questions you may have.

Yours sincerely

David Guglielmo
Country Manager

Northern Territory Inquiry into

Hydraulic Fracturing

Submission by

HALLIBURTON

29 May 2014

Halliburton Australia
Northern Territory Inquiry into Hydraulic Fracturing

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A. About Halliburton

Halliburton is a leading provider of services to the energy industry and is the global leader with respect to oil and gas production enhancement, and hydraulic fracturing (HF) in particular. Over the past 60 years, Halliburton has provided HF services for hundreds of thousands of wells around the world in a wide variety of settings and geological formations.

In more recent years, HF has been the catalyst for the ‘revolution’ in unconventional gas which has produced major economic and energy security benefits for the United States and also other nations.

At the core of Halliburton’s business is technological innovation and a very strong long-term commitment to research and development. In the area of HF, technological innovation is substantially increasing the efficiency and viability of natural gas production, and doing so in a way that minimizes environmental impact. Halliburton has a strong interest in ensuring that hydraulic fracturing operations in the Northern Territory are performed in the most environmentally responsible and effective manner possible.

By way of background on Halliburton in Australia, the company commenced operations in this country in 1958, and now employs over 1,000 staff across the country. In 2013, Halliburton spent more than $130 million on Australian vendors.

Halliburton began providing HF services in Australia in the late 1960s, and has since performed more than 2,500 jobs (in the Northern Territory, Western Australia, South Australia, Victoria, NSW and Queensland) in a broad range of conventional, unconventional and geothermal plays.

B. Overview of Unconventional Gas

The APPEA submission provides an overview of the role of shale and tight gas globally and the substantial resources identified in the Northern Territory, as well as the history and operational characteristics of HF as a critical production enhancement technology.

While HF has been used over many decades in accessing conventional gas reserves, advances in HF technology over the last 10 to 15 years in particular have seen it become critical to the recovery of oil and gas from shales and other unconventional formations, such as tight sands. These unconventional sources generally must be stimulated to produce oil or gas in commercial quantities. (In contrast, only up to 10% of coal seam gas (CSG) requires HF due to its high permeability. In Queensland, for example, since 2000 only approximately 5% of CSG wells have been hydraulically fractured.)

Natural gas development, particularly relating to unconventional gas sources where HF has been a critical technological catalyst, has yielded important social, economic and environmental benefits over recent years. In the U.S., for example:

- Natural gas prices have decreased from an average of $8.89 per MMBtu in 2008 to an expected average of $3.71 per MMBtu in 2013, primarily as a result of large-scale unconventional gas development. This has resulted in major economic benefits, both through the creation of jobs and by providing consumers lower costs for home heating and electricity. HF has boosted U.S. natural gas production by about 30 percent since 2005. Companies who use natural gas as a feedstock have built new manufacturing plants in the U.S. worth over $100 billion.

- The U.S. EPA recently noted that the increase in electric generation from natural gas has led to a decrease in the overall carbon intensity of electricity generation. (U.S. EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2011*, ES-11 http://www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2013-ES.pdf). Greenhouse gas ("GHG") emissions were lower in the United States in the first quarter of 2012 than they were during any first quarter since 1992 and overall GHG emissions in 2012 were at their lowest level since 1994, due in significant part to increased electric generation from natural gas.

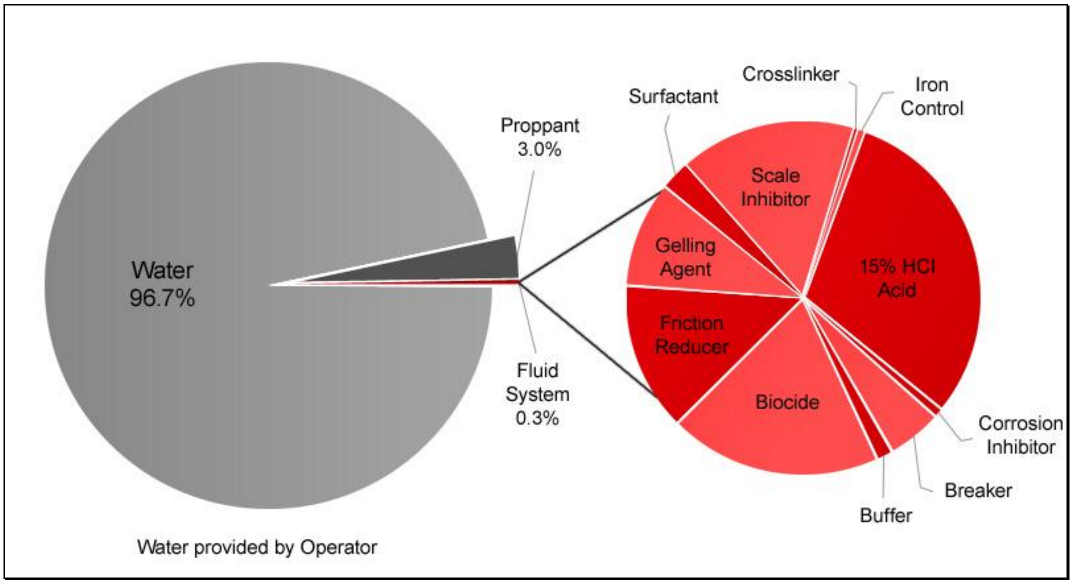
Closer to home, APPEA has determined more than 27,000 people were employed in Queensland's CSG industry in Q4 2012, and that the industry contributed over $97 million in economic flows to local communities in Queensland in 2011 and 2012. Based on this experience, it can be expected that there will be significant benefits in the Northern Territory from development of shale gas and other unconventional gas resources.

C. Hydraulic Fracturing Fluid Systems

As you are aware, HF is the practice of using highly pressured fluid to create tiny fissures in a target rock reservoir. The makeup of a fracturing fluid system for a particular well site mainly depends on the nature of the formation to be fractured, which means the specific components may vary from field to field, reservoir to reservoir and even well to well.

Water and proppant (sand) typically make up over 99% of the fracturing fluid system. The remaining small percentage is made up of chemical additives that perform a variety of functions depending on the characteristics of the formation being evaluated.

Typical formulations used in Australia by Halliburton are available at: http://www.halliburton.com/public/projects/pubsdata/Hydraulic_Fracturing/fluids_disclosure.html For instance, in the case of deep HF treatment, the following diagram presents the typical composition of a fracturing fluid formulation:



The functions served by the less than 1% of chemical additives used in a typical frac formulation include: increasing the viscosity of the fluid to improve proppant transport, reducing friction, inhibiting bacterial growth, preventing corrosion in the well casing and limiting the formation of scale and other precipitants that could impede the flow of oil and gas and fluids.

Many of the chemicals in the additives used in the process are also found in foods or in household products such as cosmetics, shampoo and cleaning products. *See* http://www.energyindepth.org/frac-fluid.pdf.

D. Benefits of Product Innovation

A critical part of the success of the unconventional gas industry in the last decade has been technological advances and innovations in HF fluids and other technologies. Where companies like Halliburton have developed innovative products, these are the result of significant investments in research and development; for example, Halliburton spent $588 million company-wide on research and development in 2013. These innovative products provide demonstrable economic benefits in terms of production enhancements as well as significant environmental benefits. For example, studies performed by Halliburton in the Marcellus Basin and the Codell Basin in the U.S. show that:

- The use of Halliburton's proprietary HF products results in an average increase in production of 33% as compared to non-proprietary stimulation fluids.
- The use of microemulsion surfactants developed by Halliburton has been found to result in long-term increases in oil and gas production of as much as 50% as compared to wells hydraulically fractured with conventional fluids.
- 24-41% more wells would need to be drilled to achieve the production enhancement that advanced technology provides.

- Halliburton's innovative products also facilitate the recycling of flowback and produced water.

See: http://cogcc.state.co.us/RuleMaking/PartyStatus/RebuttalStmts/HESIRebuttal.pdf at p. 27.

Specific HF and other product innovations by Halliburton that have led to significant environmental and production benefits include the following:

- CleanStimAUS is a fracturing fluid system made entirely of ingredients sourced from the food industry that provides exceptional fracturing and environmental performance as compared to traditional formulations.

- PermStim™ fracturing fluid provides a cleaner, more robust system than typical guar-based fluid systems. PermStim fluid is a derivatised natural polymer that contains no insoluble residue, enabling improved well clean-up and better sustained productivity.

- UniStim™ is a high performance HF fluid that is tolerant of high concentrations of total dissolved solids, including contaminants consistent with heavy produced water brines. This tolerance facilitates recycling because it allows significantly greater use of minimally treated oilfield produced and flowback water, thereby reducing demands on fresh water and the associated need for truck transportation and disposal.

- 'Frac of the Future' reduces our footprint with the use of our SandCastle vertical storage bins, which can reduce the well site size required for HF operations from about four hectares to as little as 1.2 hectares. This size reduction is accompanied by a reduction in noise and emissions through using fewer diesel engines. Reducing the number of pumping units required is reducing truck traffic to and from the wellsite. Halliburton won the 2012 World Oil HSE Award for this approach.

- CleanStream® Service treats bacteria present in the water provided at the well site with ultraviolet light instead of the biocides that are commonly used. In many cases, the CleanStream process can be 99.9% effective, dramatically reducing the need for chemical biocides.

- ADP™ Advanced Dry Polymer Blender enables mixing any of Halliburton's fracturing fluids using a dry polymer, eliminating the need for liquid gel concentrates and resulting in conservation of petrochemical materials and reduced vehicle miles travelled transporting liquid gelled material. During 2012, the use of ADP blenders and associated dry gel removed over 30 million gallons of hydro-treated light petroleum distillates from HF fluid in North America.

- WellLock Resin is an advanced cementing product developed by Halliburton with significant environmental benefits. WellLock resin is a synthetic thermosetting polymeric material that helps control and prevent annular flow, thereby protecting against potential migration of gas and water. Unlike other resins, WellLock resin is non-flammable and tolerates water (i.e. does not react exothermically) and is designed to work with aqueous-based fluids (i.e. water-based muds, cement slurries).

In short, these and other technologies minimize the use of chemicals, promote recycling, limit fresh water requirements, and reduce traffic and air emissions as well as surface disturbances while enhancing production, resulting in a reduced overall footprint. The recognition and protection of proprietary information in a balanced regulatory framework provides the basis for companies to invest in ongoing technological innovation.

E. Disclosure Through FracFocus

Halliburton supports public disclosure of fracturing fluid ingredients and has taken a number of steps to provide the public with information regarding the chemicals used in HF operations, including supporting the disclosure of information through the FracFocus Hydraulic Fracturing Chemical Disclosure Registry ("FracFocus") website: http://fracfocus.org.

FracFocus is a web-viewable system used to obtain, store, and publish information concerning the chemicals used in HF. In the U.S., FracFocus is a joint project of the Ground Water Protection Council ("GWPC") and the Interstate Oil and Gas Compact Commission ("IOGCC"). Halliburton has supported the use of FracFocus as a platform for providing the public with information regarding the fluids used in hydraulically fracturing individual wells. FracFocus has been very successful in the U.S. and Canada and is currently being considered by regulators in the EU and Australia.

The key characteristics of FracFocus are as follows:

- It allows companies to post information about chemicals used in the fracturing of oil and gas zones on a well-by-well basis. Companies upload HF fluid composition information and the data is made publicly available (no registration required) and searchable at http://fracfocus.org.

- The disclosure form is geographically tagged to allow the public and regulators to find and view information about wells based on their location. The system allows website users to locate wells by state, county, coordinates, a unique identifier known as an American Petroleum Institute ("API") number, well name and number, Chemical Abstracts Service ("CAS") number, and ingredient (chemical) name.

- The FracFocus disclosure information identifies the base fluid and additive products used to fracture a well and includes information concerning the constituents of those additive products such as ingredient names, CAS numbers, and maximum ingredient concentration in the overall HF fluid. FracFocus allows for companies to protect confidential business information through the use of general chemical descriptors in lieu of providing specific chemical identities for certain proprietary ingredients. The chemical identity and concentration information provided on FracFocus along with hazard information provided by MSDSs is sufficient in many instances to allow regulators to perform any necessary assessments.

- FracFocus has received over 72,000 disclosure records from 600 different companies and has been visited by over 750,000 people from over 134 countries.

- FracFocus has functioned effectively as a voluntary reporting mechanism. At the same time, 22 U.S. states, representing 80% of U.S. onshore oil production and 92% of gas production, and the US' federal Bureau of Land Management have either proposed or have already opted to require or allow companies to use FracFocus to meet state reporting requirements.

- FracFocus has been a successful regulatory tool in the U.S. and Canada because it allows regulators to provide information regarding the fluids used in hydraulically fracturing individual wells to interested members of the public and at the same time obtain information to support various regulatory functions. It is sufficiently flexible that a number of different states have been able to use it to meet their needs.

F. Environment Risk Assessment and Mitigation Issues

The Inquiry's terms of reference raise a number of specific matters for comment. Halliburton offers views on a number of these issues as follows:

Historical and Proposed Use of HF in the Northern Territory

Halliburton has undertaken one HF project in recent years in the Northern Territory. This was conducted for Falcon Oil and Gas in 2011. It is also understood that HF treatment was applied to several wells in the early 1990s by the company for Santos at Mereenie.

Environmental Outcomes from HF Activities in the Northern Territory

In addition to the HF project for Falcon Oil and Gas noted above, in recent years Halliburton has undertaken HF activities in unconventional formations in other states, including Queensland, New South Wales and Western Australia. Based on its review of records for the last five years, none of the HF operations in which Halliburton has engaged in the NT or other states over that period has resulted in significant adverse environmental outcomes. There have been no incidents in which the fracturing fluids pumped down the wellbore are known or suspected to have entered shallow aquifers. Any surface spills that have occurred have been limited in size and none has impacted groundwater.

Frequency of Types and Causes of Environmental Impacts From HF in the Northern Territory and Similar Deposits in Other Parts of the World

The key environmental risk issue that has been raised over recent years in relation to HF is the protection of groundwater. APPEA's submission to the Inquiry discusses the steps taken in the well construction process to protect groundwater and mitigate against the risk of HF fluids contaminating drinking water sources. In over 60 years in which more than 2.5 million wells have been hydraulically fractured internationally there is no confirmed evidence that this type of contamination has ever occurred.

We have consolidated below for your information a range of statements and studies from Australian authorities, U.S. Federal officials, U.S. State government agencies, and others to corroborate that there is little or no risk of fracturing fluids contaminating groundwater.

(a) U.S. Federal and International Studies

- A U.S. EPA study of allegations of contamination from hydraulic fracturing of coalbed methane ("CBM") wells "did not find confirmed evidence that drinking water wells have been contaminated by hydraulic fracturing fluid injection into CBM wells." U.S. EPA, *Evaluation of Impacts to Underground Sources of Drinking Water by Hydraulic Fracturing of Coalbed Methane Reservoirs*, ES-1 (2004), available at http://water.epa.gov/type/groundwater/uic/class2/hydraulicfracturing/wells_coalbedmethanestudy.cfm.

- The U.S. Geological Survey released a study in January 2013 that examined groundwater samples representing approximately one-third of the Fayetteville Shale gas production area and found no regional effects on groundwater from activities related to gas production. Kresse, T.M. et al., *Shallow groundwater quality and geochemistry in the Fayetteville Shale gas-production area, north-central Arkansas, 2011*, U.S. Geological Survey Scientific Investigations Report 2012-5273 (Jan. 2013), available at http://pubs.usgs.gov/sir/2012/5273/sir2012-5273.pdf.

- A peer-reviewed paper by researchers at the Lawrence Berkeley National Laboratory reports on some of the results of modeling being conducted for EPA's study of the impacts of HF on drinking water and concludes that the possibility of hydraulically induced fractures at great depths causing activation of faults and creation of a new flow path that can reach shallow groundwater resources is "remote." Rutqvist, J., et al., "Modeling of fault reactivation and induced seismicity during hydraulic fracturing of shale-gas reservoirs," *Journal of Petroleum Science and Engineering* (2013), available at http://dx.doi.org/10.1016/j.petrol.2013.04.023.

- The New Zealand Parliamentary Commissioner for the Environment issued a report in 2012 finding that "there is no evidence that fracking has caused groundwater contamination in New Zealand." Government of New Zealand, Parliamentary Commissioner for the Environment, *Evaluating the environmental impacts of fracking in New Zealand: An interim report*, 43 (Nov. 2012), available at http://www.pce.parliament.nz/publications/all-publications/evaluating-the-environmental-impacts-of-fracking-in-new-zealand-an-interim-report/.

- In a May 2012 report, the Council for the Taranaki Region in New Zealand found that there was no evidence of environmental problems related to the HF operations that had been undertaken in the region over a period of almost 20 years and that there is little risk to freshwater aquifers from properly conducted HF operations. Government of New Zealand Taranaki Regional Council, *Hydrogeologic Risk Assessment of Hydraulic Fracturing for Gas Recovery in the Taranaki Region*, 3-4 (May 2012), available at http://www.trc.govt.nz/assets/Publications/guidelines-procedures-and-publications/hydraulic-fracturing/hf-may2012-graph-p19.pdf.

- The South African Department of Mineral Resources has stated that there are "no documented cases of properly placed hydraulic fracturing fluids migrating through the overlying strata to contaminate groundwater." The Department found that "potable aquifers are expected to be far removed from shale gas target formations and safe from contamination from injected fracking fluids, as the latter are immobile under normal conditions with no 'drive' once the fracturing operation is completed." Republic of South Africa, Department of Mineral Resources, *Investigation of Hydraulic Fracturing in the Karoo Basin of South Africa*, 31 (July 2012), available at http://www.dmr.gov.za/publications/summary/182-report-on-hydraulic-fracturing/852-executive-summary-investigation-of-hydraulic-fracturing-in-the-karoo-basin-of-south-africa.html.

- The United Kingdom Department of Energy and Climate Change concluded in a December 2013 report that groundwater contamination from HF "has not been observed in practice and would be unlikely" and that "it is considered reasonable to suggest that any risk of contamination from fracturing activities is exceptionally low." AMEC Environment & Infrastructure UK Limited, Department of Energy and Climate Change, *Strategic Environmental Assessment for Further Onshore Oil and Gas Licensing*, 96 (Dec. 2013), available at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/273997/DECC_SEA_Environmental_Report.pdf.

- The Energy and Climate Change Committee appointed by the British House of Commons concluded in May 2011 that "hydraulic fracturing itself does not pose a direct risk to water aquifers, provided that the well-casing is intact before this commences." United Kingdom Parliament, House of Commons, Energy and Climate Change Committee, *Fifth Report: Shale Gas* (May 10, 2011), available at http://www.publications.parliament.uk/pa/cm201012/cmselect/cmenergy/795/79502.htm.

(b) Statements by Australian and U.S. Federal Officials

- The Western Australia Department of Mines and Petroleum has stated that "[s]ince 1958, more than 780 petroleum wells have undergone fracture stimulation in WA with no known adverse effects on the environment, water sources or peoples' health." WA Department of Mines and Petroleum, *Natural Gas from Shale and Tight Rocks Fact Sheet: Providing responses to misinformation* (August 2013), available at http://www.dmp.wa.gov.au/shaleandtightgas.

- Then-EPA Administrator Lisa Jackson stated in testimony before the House Committee on Oversight and Government Reform that she was "not aware of any water contamination associated with the recent drilling" in the Marcellus Shale. *Pain at the Pump: Policies that Suppress Production of Oil and Gas*, Hearing Before the H. Comm. on Oversight & Gov't Reform, Rep. No. 112-54, 87 (May 24, 2011), available at http://www.gpo.gov/fdsys/pkg/CHRG-112hhrg70675/pdf/CHRG-112hhrg70675.pdf. She again made statements to the press on April 30, 2012 that "in no case have we [EPA] made a definitive determination that [hydraulic fracturing] has caused chemicals to enter groundwater." *See* https://www.youtube.com/watch?v=_tBUTHB_7Cs.

- Then-U.S. Bureau of Land Management ("BLM") Director Bob Abbey stated that he had "never seen any evidence of impacts to groundwater from the use of fracing technology on wells that have been approved by" BLM. *Challenges Facing Domestic Oil and Gas Development: Review of Bureau of Land Management/U.S. Forest Service Ban on Horizontal Drilling on Federal Lands*, Hearing before the Subcomm. on Energy and Mineral Resources of the H. Comm. on Natural Resources and the Subcomm. on Conservation, Energy and Forestry of the H. Comm. on Agriculture, 112th Cong. (July 8, 2011), available at http://www.gpo.gov/fdsys/pkg/CHRG-112hhrg72151/pdf/CHRG-112hhrg72151.pdf.

- U.S. Department of Energy Secretary Ernest Moniz made remarks to the press on August 1, 2013 that, "to my knowledge, I still have not seen any evidence of fracking per se contaminating groundwater." *See* http://thehill.com/blogs/e2-wire/e2-wire/315009-energy-secretary-natural-gas-helps-battle-climate-change-for-now.

(c) Studies and Statements from U.S. State Governments and Agencies

- In 1998 the U.S. Ground Water Protection Council surveyed 25 state agencies responsible for oil and gas development and found that there was not a single substantiated claim of contamination of drinking water supplies attributable to hydraulic fracturing. Ground Water Protection Council, *Survey Results on Inventory and Extent of Hydraulic Fracturing in Coalbed Methane Wells in the Producing States* (1998), available at https://cogcc.state.co.us/RuleMaking/PartyStatus/FinalPrehearingStmts/HESIExhibits.PDF.

- The Interstate Oil and Gas Compact Commission ("IOGCC") surveyed its state regulatory agency members in 2002 and found that nearly one million wells had been hydraulically fractured over the course of several decades but again found no evidence of substantiated claims of contamination of drinking water supplies due to hydraulic fracturing. IOGCC, *States Experience with Hydraulic Fracturing: A Survey of the Interstate Oil and Gas Compact Commission* (2002), available at http://www.mde.state.md.us/programs/Land/mining/marcellus/Documents/Interstae_Oil_Gas_Compact_Commission_States_Experience_w_Hydraulic_Fracturing_2002.pdf. IOGCC continues to confirm on its website that "IOGCC member states have all stated that there have been no cases where hydraulic fracturing has been verified to have contaminated drinking water." *See* http://www.iogcc.state.ok.us/hydraulic-fracturing.

- In 2011, several states reported no evidence of groundwater contamination from hydraulic fracturing:

    - The New York State Department of Environmental Conservation reported that there are "no known instances of groundwater contamination have occurred from previous horizontal drilling or hydraulic fracturing projects in New York

State." New York State Department of Environmental Conservation, *Revised Draft Supplemental Generic Environmental Impact Statement on the Oil, Gas and Solution Mining Regulatory Program*, 6-47 (2011), available at http://www.dec.ny.gov/energy/75370.html. In reaching this conclusion, NYSDEC relied in part on the statements of regulatory officials from 15 states – including Colorado, New Mexico, Pennsylvania, Ohio, Texas and Wyoming – that hydraulic fracturing operations have not led to groundwater contamination. *Id*. at 6-41.

  - The Alaska Oil and Gas Conservation Commission affirmed that "[i]n over fifty years of oil and gas production, Alaska has yet to suffer a single documented instance of subsurface damage to an underground source of drinking water." Alaska Oil and Gas Conservation Commission, *Hydraulic Fracturing in Alaska* (Apr. 6, 2011), available at http://doa.alaska.gov/ogc/reports-studies/HydraulicFracWhitePaper.pdf.

  - The Colorado Oil and Gas Conservation Commission ("COGCC") director stated in responding to questions from the Senate Committee on Environment and Public Works: "we have found other instances where activities associated with oil and gas operations have impacted water supplies. These events have typically been tied to incidents such as a leaking storage pit, a poorly cemented oil and gas well, or leaking production equipment. These cases, however, have not been linked to the specific act of hydraulic fracturing hydrocarbon layers thousands of feet below the surface, and typically, thousands of feet below groundwater supplies." David Neslin, *Written Answers to Follow-up Questions from the Senate Committee on the Environment and Public Works* (May 17, 2011), available at http://cogcc.state.co.us/Announcements/Hot_Topics/Hydraulic_Fracturing/EnviroPublicWorksQA.pdf.

- In 2012, regulators from a number of states – including Arkansas, Colorado, Louisiana, North Dakota, Ohio, Oklahoma, Pennsylvania and Texas – confirmed to the U.S. Government Accountability Office that, based on state investigations, the HF process had not been identified as a cause of groundwater contamination in their states. U.S. GAO, *Information on Shale Resources, Development and Environmental and Public Health Risks*, 49 (Sept. 2012), available at http://www.gao.gov/assets/650/647791.pdf.

- California regulators have been quoted in recent years saying that the state has never experienced groundwater contamination from hydraulic fracturing. In 2012, a Division of Oil, Gas and Geothermal Resources official stated "there is no evidence of harm from fracking in groundwater in California at this point in time. And it has been going on for many years." *See* http://www.mercurynews.com/ci_22219233/california-releases-first-ever-fracking-regulations. In 2013, the Director of the California Department of Conservation stated "[i]n California it has been used for 60 years, and actively used for 40 years, and in California there has been not one record of reported damage directly to the use of hydraulic fracturing." *See* http://www.nationaljournal.com/new-energyparadigm/california-s-top-oil-regulator-on-fracking-climate-change-and-fossil-fuels-20131016.

- In 2013, a Michigan Department of Environmental Quality official stated that "As far as migration of gas or fracture fluids, we have never seen an instance where a fracture communicates directly with the fresh water zone." *See* https://www.youtube.com/watch?v=A979CqCeH00.

(d) Other Statements and Studies

- Dr. Mark Zoback, Professor of Geophysics, Stanford University and member of the Shale Gas Production Subcommittee of the Secretary of Energy Advisory Board stated that "[f]racturing fluids have not contaminated any water supply and with that much distance to an aquifer, it is very unlikely they could." *See* http://news.stanford.edu/news/2011/august/zoback-fracking-qanda-083011.html.

- The Royal Society concluded in a June 2012 report that a variety of factors constrain fracture height growth and that while it might be theoretically possible to create pressures that would allow a fracture to grow vertically to shallow depths, the "volume of fluid injected is simply insufficient by orders of magnitude to create these pressures" and that "such an enormous pressure could not be sustained." The report also found that "[u]pward flow of fluids from the zone of shale gas extraction to overlying aquifers via fractures in the intervening strata is highly unlikely" and that, in general, it is "very difficult to conceive" how such upward fluid flow might occur given the hydrogeological conditions found in the relevant areas of the U.K. The Royal Society, *Shale gas extraction in the UK: a review of hydraulic fracturing* (June 2012), available at https://royalsociety.org/~/media/policy/projects/shale-gas-extraction/2012-06-28-shale-gas.pdf.

- MIT performed a study in 2011 on the potential risks of hydraulic fracturing to groundwater aquifers and found that "no incidents of direct invasion of shallow water zones by fracture fluids during the fracturing process have been recorded." MIT Energy Initiative, *The Future of Natural Gas: An Interdisciplinary MIT Study*, Appx. 2E (2011), available at https://mitei.mit.edu/publications/reports-studies/future-natural-gas.

- An October 2012 report regarding HF operations in the Inglewood Oil Field in the Baldwin Hills area of Los Angeles County showed that, based on actual groundwater monitoring results, the groundwater quality in the area was not affected by HF activities. Cardno Entrix, *Hydraulic Fracturing Study: PXP Inglewood Oil Field* (Oct. 2012), available at http://www.inglewoodoilfield.com/fracturing-study/.

- Gradient's 2013 National Human Health Risk Evaluation evaluates whether it is possible for fluids pumped into a tight formation during the HF process to migrate upward to reach drinking water aquifers. Gradient determined that once the fracturing fluids are pumped into a tight formation, it is "simply not plausible" that the fluids would migrate upwards from the target formation through several thousand feet of rock to contaminate drinking water aquifers. Gradient, *National Human Health*

Risk Evaluation for Hydraulic Fracturing Fluid Additives (May 1, 2013), available at http://www.energy.senate.gov/public/index.cfm/files/serve?File_id=53a41a78-c06c-4695-a7be-84225aa7230f

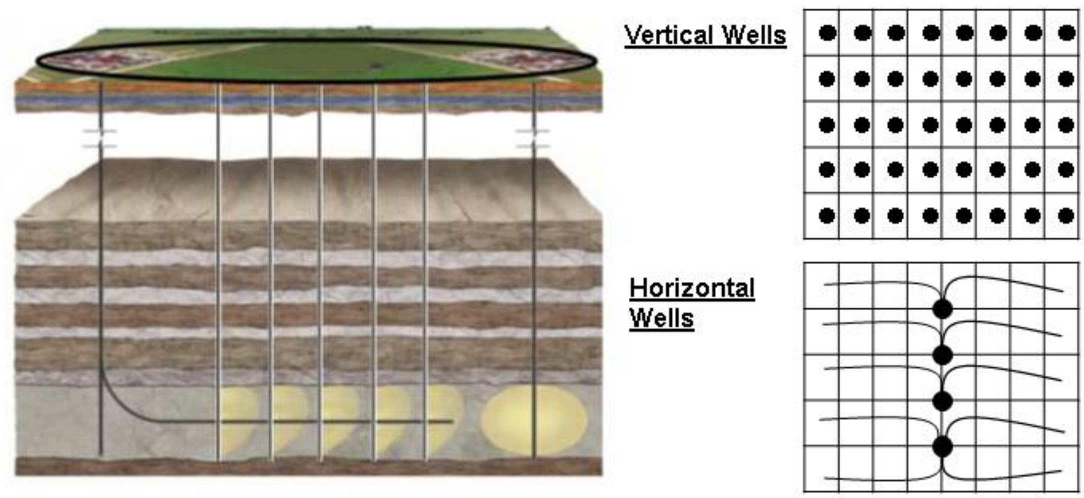
- A peer-reviewed paper by Gradient discusses the physical constraints on upward fluid migration from black shales to shallow aquifers and concludes that upward migration of frac fluid and brine as a result of HF activity does not appear to be physically possible. Flewelling & Sharma, "Constraints on Upward Migration of Hydraulic Fracturing Fluid and Brine," *Groundwater* (Jul. 29, 2013), available at http://onlinelibrary.wiley.com/doi/10.1111/gwat.12095/abstract.

- Another peer-reviewed paper by Gradient and a Halliburton expert concludes that it is not physically plausible for induced fractures to create a hydraulic connection between tight formations at depth and overlying drinking water aquifers, even through connections with existing faults. Flewelling et al., "Hydraulic fracturing height limits and fault interactions in tight oil and gas formations," *Geophysical Research Letters* (Jul. 26, 2013), available at http://onlinelibrary.wiley.com/doi/10.1002/grl.50707/abstract.

In light of this extensive evidence, the report on unconventional gas production issued by the Australian Council of Learned Academies notes that the consensus among experts is that, despite significant public concerns about risks to groundwater, the primary risk is to surface water. However, this risk is carefully managed. As the ACOLA report states, "the industry takes great care to avoid spillage" and "already has rigorous systems for dealing with spillage, or from the incorrect disposal of the hydraulic fracturing fluid." Australian Council of Learned Academies, *Engineering Energy: Unconventional Gas Production* (May 2013), at 16, 112, 131.

The Potential for Multiple Well Pads to Reduce/Enhance Risks of Environmental Impact

Many installations for production now utilise multiple horizontal wells drilled at a common well pad in order to maximize oil and gas production and minimize the amount of land disturbance when developing the well network to extract the oil and/or natural gas. Well pads for multi-well installations may vary somewhat in size, depending on the number of wells installed and whether the operation is in the drilling or production phase. As discussed in the APPEA submission, six to twelve horizontal wells can be drilled from a single wellpad.



Horizontal drilling and hydraulic fracturing reduce the "footprint" of natural gas operations by 400 percent over operations involving vertical wells. This is because with one well pad at the surface, horizontal drilling using hydraulic fracturing can extract the amount of natural gas that would take a number of well pads to extract using vertical drilling only. This reduction in surface use to an area of approximately a hectare has ancillary benefits in terms of less truck traffic, reduced air emissions, a lower risk of spills and stormwater runoff, and reduced use of resources overall.

Relationship Between Environmental Outcomes of HF of Shale Petroleum Deposits with Geology, Hydrogeology and Hydrology

The environmental outcomes of hydraulic fracturing of shale gas or shale oil deposits can be influenced by the geology, hydrogeology and hydrology at and in the vicinity of the well site. For example, one consideration in designing an HF operation is the depth of drinking water aquifers relative to the anticipated height of induced fractures; in areas where the separation between the target zone and shallow aquifers is limited (conditions that are more likely to be encountered with coal seam gas and that are unlikely to be encountered in Northern Territory shale or tight gas plays), the design of an HF operation must be carefully considered. In addition, the location of faults must be taken into account; these areas are generally avoided for a variety of reasons and are unlikely to be the site of HF operations in the first place.

At the same time, sedimentary basins that are the focus of shale plays around the world share a number of characteristics that ensure that the likelihood of fracturing fluids migrating from the target zone to shallow aquifers is remote. Gradient undertook an extensive analysis of the potential risks to drinking water associated with the use of HF fluids in 2013, evaluating whether it is possible for fluids pumped into a tight formation during the HF process to migrate upward to reach drinking water aquifers. Gradient, *National Human Health Risk Evaluation for Hydraulic Fracturing Fluid Additives* (May 1, 2013) ("Gradient 2013 Study"), available at http://www.energy.senate.gov/public/index.cfm/files/serve?File_id=53a41a78-c06c-4695-a7be-84225aa7230f. Gradient determined that once the fracturing fluids are pumped into a tight formation, it is simply not plausible that the fluids would migrate upwards from the target formation through a thousand meters or more of rock to contaminate drinking water aquifers.

Gradient found that there are a variety of factors that contribute to the implausibility of this scenario:

- Tight oil and gas formations are found in geologic settings that greatly restrict upward fluid movement due to the presence of multiple layers of low permeability rock. Because studies show that fractures remain at least 500 metres – and usually more than a thousand metres – below the surface fluids would have to migrate an extended distance through multiple layers of rock, many of very low permeability, in order to reach shallow aquifers;

- Another factor inhibiting upward fluid migration is the inherent tendency of the naturally-occurring formation water (brines) to sink and form a stable layer below rather than mingle with or rise above fresh water (density stratification). In order for the fracturing fluids and brines to reach fresh drinking water aquifers, the fluids would have to overcome this natural stratification. However, upward hydraulic gradients that might otherwise be sufficient to overcome this stratification are found only where there is an overlying rock layer of very low permeability, which essentially prevents any upward fluid movement. The effect of these constraints is demonstrated by the fact that the oil and gas and the brines have been trapped in the target formation for millions of years;

- The HF process itself does not create conditions that would overcome these natural restrictions on fluid movement because the associated pressures are too short-term and localized to push fluids through hundreds or thousands of metres of low permeability rock. A typical HF stage lasts only 1-2 hours, and the pressures exerted extend only about 3 meters from the fractures that are created. Moreover, any fluids introduced into a deep shale formation typically will be soaked up and trapped within the shale by natural capillary forces. At the same time, the removal of brine and oil/gas from the well during long-term production reduces the pressure in the target formation near the wellbore over a period of years, meaning that any fluid flow will be in that direction (*i.e.*, towards the wellbore or towards lower pressure in accordance with Darcy's Law). Therefore any remaining fluids would be drawn to the wellbore and would not be likely to migrate away;

- The fractures created during HF are of limited height. This is confirmed by microseismic data from over 12,000 HF operations in shale plays and other formations across the U.S. which show that the "tallest" fracture was less than 600 metres in height with typical fracture heights being far less (the median fracture height was less than 80 meters), and in all cases there were at least 500 metres (and usually more than a thousand meters) of intact bedrock above the fractures. These data are consistent with the limits on fracture height growth suggested by basic geophysical principles, which indicate that fracture heights are limited by fracturing fluid volume and that the amount of fluid used in an HF operation is simply insufficient to propagate a fracture from the typical depth of a shale formation upward to a depth that is anywhere close to drinking water aquifers;

- Additional factors limiting fracture height growth include (i) the existence of stress contrasts between sedimentary layers, which tend to limit the growth of fractures into adjacent layers, (ii) the creation of fracture networks and the leakoff of fracturing fluids that results in the energy created during HF operations by the fluid pressure being spread across multiple fractures rather than being concentrated in driving a single fracture to its maximum possible height, and (iii) the tendency of fractures to become horizontal rather than vertical at shallower depths (above about 600 metres below ground surface). In fact, the few fractures in the extensive database mentioned above that were shallower than 600 metres below ground surface showed essentially no height growth. *See also* Fisher & Warpinski, *Hydraulic Fracture Height Growth: Real Data*, Society of Petroleum Engineers SPE 145949 (Feb. 2012), available at http://www.spe.org/atce/2011/pages/schedule/tech_program/documents/spe145949%201.pdf; and

- The same microseismic data show that – despite speculation to the contrary – the presence of natural faults in the bedrock does not significantly contribute to the upward movement of fluids. The data indicate that existing faults are activated to only a very limited extent (movement over a distance of less than 20 metres) during HF operations, resulting in very little additional fluid movement beyond the movement through induced fractures.

Gradient stated that its analysis covered a wide range of sedimentary basins in the U.S. with different characteristics and would apply to sedimentary basins around the world with similar characteristics.

Gradient also analyzed the potential for spills of HF fluids (or flowback fluid) to reach drinking water wells or surface waters. Using a "probabilistic" approach to address a wide range of spill scenarios and hydrologic conditions as well as very conservative assumptions (e.g., no spill mitigation measures in place and no adsorption of chemical constituents to the soil or degradation in the environment), Gradient determined the concentrations at which HF constituents might be found in surface water or a drinking water well as a result of a spill and compared them to levels at which health effects might become a concern. Gradient found that any human health risks would be insignificant because various dilution mechanisms would further reduce the already low concentration levels of HF constituents before they ever reached drinking water sources.

In short, while local conditions should be considered, the common characteristics of sedimentary basins, generally applicable geological and hydrogeological principles and the nature of HF operations mean that the environmental outcomes of hydraulic fracturing of shales and other tight formations will not involve adverse human health impacts to groundwater or surface water.

Potential for Regional and Area Variations of the Risk of Environmental Impact from HF in the Northern Territory

While shale formations targeted for oil and gas production in North America and Australia differ in a number of particulars such as the thickness of the shale layers, they are all part of sedimentary basins that have the same fundamental layered structure, and – as discussed above – the same basic hydrogeological principles that constrain fluid movement in shales and overlying formations in the U.S. and Canada would apply in Australia.

The risk of a sub-surface connection between fractured horizons and water resource aquifers is influenced by geology. Whilst the geologies overall may be significantly different, the factors influencing the environmental risk are rather similar. The separation between the fractured horizon and the overlying resource aquifer of concern is the most important parameter. Not unlike the shale plays in the U.S., the shales in the Macarthur, Bonaparte, Beetaloo, Georgina and Amadeus Basins that are expected to be targeted for exploration and production are typically separated from aquifers by one to two kilometres of rock, which is significantly more than even the tallest fractures in the extensive U.S. database.

It is important to understand the specific stratigraphy of each well, because they are all different. Current processes for assessing risk on a well by well basis prior to HF means that this is being considered every time a well is fracced. As in other shale plays, the accumulation of detailed information regarding geological conditions in areas being explored will allow industry members to further refine their HF designs and make operations more efficient.

Development of better well construction practices, and many years of experience means Northern Territory wells are likely to be of a more uniformly high standard. Because exploration of the Territory's shale and tight gas plays is at the development stage, all the wells will be newly installed. Fraccing old wells (which has occurred in some places in the US) is not likely to occur in the Territory. As a result, wellhead failures and leakage from casings are proportionately less likely.

US experience shows that surface management procedures are at least as important as understanding subsurface geology in managing environmental risk. Many years of operating practice in the US, as well as technology development, results in Australian operations benefiting from these lessons. Evidence is that most environmental incidents have been the result of releases from surface rather than leakage down-hole. As noted above, the ACOLA report recognizes that industry takes great care to avoid spillage, and strict regulations are in place to address these situations.

Effective Methods for Mitigating Potential Environmental Impacts Before, During and After HF with Reference to:

(a) the selection of sites for wells;

Selection of well sites is the responsibility of the operator. Halliburton supports the selection of well sites that will allow safe and efficient natural gas production with minimal surface impact.

(b) well design, construction, standards, control and operational safety;

The construction of an oil or natural gas well is undertaken in accordance with government regulatory regimes as well as industry standards (such as those developed by API and APPEA) and other good engineering practices.

In the Northern Territory, well integrity is assessed as part of the process to ensure environmental and safety objectives are achieved before operations to drill commence. The *Schedule of Onshore Petroleum and Production Requirements 2012* (Schedule of Requirements) prescribes specific minimum standards and prescriptive requirements for petroleum activities, including in respect to well casing and cementing. It also incorporates international standards developed by API. For example, design of well casing must conform to API Bulletin 5C2 ('Bulletin on Performance Properties of Casing Tubing and Drill Pipe').

Multiple layers of cement and steel casings provide zonal isolation – not only to protect the groundwater but also to provide safe conduits for operations – including placing fracturing treatments in the desired formation.

Studies have concluded that the probability of fracture fluids reaching an underground source of drinking water due to failures in the cementing or casing of a properly constructed well is estimated at less than 1 in 50 million wells. *See* http://www.nyserda.ny.gov/Publications/Research-and-Development-Technical-Reports/Other-Technical-Reports /Natural-Gas-Environmental-Impact.aspx at p. 21.

There have been isolated incidents unrelated to HF that have been caused by improperly constructed wells. Recent studies confirm that even the risk of such incidents is very low. *See* http://fracfocus.org/mwg-internal/de5fs23hu73ds/progress?id=iCSnzXuXSZ.

There is considerable literature available on well integrity and barrier failure of oil and gas wells, primarily in respect to the United States experience. Halliburton considers that the recent paper *Environmental Risk Arising From Well-Construction Failure – Differences Between Barrier and Well Failure, and Estimates of Failure Frequency Across Common Well Types, Locations and Well Age* (King & King, 2013) will assist the Inquiry on the topic of well leak statistics and other matters. A copy of the King and King 2013 paper is enclosed with this letter.

The King & King paper is a recent, peer approved publication, and considers an extensive data set of 600,000 wells worldwide. It not only identifies failure rates, but explains the key factors contributing to well failures. The data set available allows a conclusion to be drawn in respect to the overall frequency of leaks from wells and the risk that leaks pose to groundwater. However, it does not quantify the volumes of above surface or subsurface leaks into the outside formation arising from any incidents. Particular summary points that may be of interest to this Inquiry include:

- Oil and gas wells are comprised of multiple layers of steel, cement, seals and valves, providing multiple barriers between well fluids, oil or gas and the surrounding environment. Well design is a geomechanical, fit-for-purpose engineering exercise, with design taking account of unknowns associated with the outside formation and worst-case loads and forces. Wells are engineered to both warn of a potential problem and prevent the occurrence of a problem. One or more individual barriers of a well may fail without creating a pathway to the outside formation and the potential for impact to the environment or groundwater.

- The paper differentiates between individual barrier failures and well integrity failure when all barriers fail, giving rise to the possibility of a leak. While there is considerable variability in failure rates across the globe, King & King conclude that oil, gas or injection wells constructed to current standards have an overall leak frequency ranging from 0.005 to 0.03%. These well integrity failure rates are two to three orders of magnitude less than for single barrier failures. King & King also conclude that the overall risk of pollution to groundwater from producing wells is extremely low.

- The paper refers to a previous study of groundwater contamination incidents relating to 65,000 wells in Ohio and 250,000 wells in Texas[1]. That study identified no incidents that directly involved hydraulic fracturing. The data indicate that historical environmental incidents associated with oil and gas development are more commonly associated with above ground issues – fluid handling, leaking tanks or flowlines or use of surface pits to contain fluids.

- The most common leak points for producing wells are at the surface, such as failed gaskets or valves, which can be easily repaired. Outward subsurface leaks are uncommon due to the lower pressure gradient in the well compared to the outside formation. Where subsurface leaks occur, these are more likely water from the outside formation leaking into the well.

- The most important factors contributing to well integrity failure are well age and construction era. A number of historical issues identified in the King & King paper will not represent risks in the Northern Territory context, given the early stage of development of the industry here.

In addition, a failure of the cement (if it occurs) is not likely to create a pathway for migration of fracturing fluid up the well annulus to shallow depths. Water is the wetting fluid in shales and the large capillary forces in predominantly oil- and gas-saturated shale would more likely draw fluid into the rock pore spaces (a process called imbibition). Moreover, fracturing fluid is typically denser than shallow groundwater (especially after mixing with naturally-occurring brine near the targeted formations) and migration through a compromised cement barrier toward the surface would not occur in the absence of a mechanism to force the dense fluid upward; this type of mechanism would generally not be present in the vicinity of a producing well, which creates a low pressure zone near the wellbore and draws fluids toward the well rather than allowing them to migrate up along the casing. Moreover, extraction of oil and gas leads to a significant pressure reduction in the targeted formation that is expected to diminish any naturally preexisting elevated pressure (if present), such that there would not be a long term driving force for upward migration of dense fracturing fluid after a well is plugged and abandoned.

(c) well integrity ratings;

Cement bonds play a critical role in isolating the oil/gas well from other subsurface formations, including water-bearing formations. Monitoring of these seals, referred to as cement bond integrity logging, is conducted to confirm the presence and the quality of the cement bond between the casing and the formation. Such logging is typically conducted using a variety of

[1] *State Oil and Gas Agency Groundwater Investigations and Their Role in Advancing Regulatory Reforms, A Two State Review: Ohio and Texas* (Groundwater Protection Council, Kell 2012).

electronic devices for each cement bond associated with the well (API, 2009). By following these well installation and testing best practices, wells are carefully constructed, with a number of key design and monitoring elements (*e.g.*, well casings/cement bonds, logging to ensure the adequacy of cementing, and pressure integrity testing). These practices protect drinking water aquifers by achieving full zonal isolation from overlying formations.

Prior to commencing the HF treatment, the well casing and all equipment to be used in the process (*e.g.*, pumps, high pressure lines) are pressure tested to ensure that they can withstand the pressure to be applied during HF. Any leaks observed during such testing are addressed. The pressure testing of equipment helps to minimize the likelihood of any fluid spills during the HF process.

Halliburton supports the efforts of the operators to employ best practices and comply with all applicable requirements for well testing and monitoring to ensure well integrity.

(d) water use;

A single HF process for a horizontal well typically uses 11 to 19 million litres of water. In Australian tight-gas vertical wells, the amount of water used in hydraulic fracturing is substantially less, typically in the order of several hundred thousand litres or less. For Australian vertical shale wells, the water volumes tend to be similar to those of the designs for the horizontals.

Industry recycling efforts minimise fresh water consumption and the costs associated with procurement and disposal, as well as trucks needed to transport water to well sites, meaning less impact on rural communities. In the US, millions of litres of water are currently being treated and reused. For example, regulators in Pennsylvania recently reported that operators in the Marcellus Shale region of the state are recycling up to 90% of their flowback and 65% of their produced water. Halliburton has also assisted its customers in resolving water supply challenges through technology, including the development of fluid systems that use briny or salty water as the base fluid instead of fresh water.

(e) chemical use;

In Section C of this letter, Halliburton has provided information on the use of chemicals in HF, including the small concentrations of chemicals present in an overall fluid formulation. We have also explained the nexus between ongoing product innovation and advancement in HF fluid technologies and the substantial improvements that have been made in environmental performance.

The most effective way to mitigate any potential impacts from hydraulic fracturing and prevent exposure to the chemicals used in HF operations are the use of best well integrity practices described above. Halliburton supports the efforts of the operators to employ these best practices for well integrity and perform the monitoring and testing exercises described in subsections (c) and (i).

In addition, Halliburton makes it a priority to prevent and mitigate surface spills of its HF fluids through its ‘Journey to ZERO’ program, the goal of which is to eliminate environmental and safety incidents. Halliburton likewise supports the efforts of its operators to prevent and mitigate any surface spills at the well pad. Accidental surface spills that may result from storage or use on-site are expected to result in negligible or very small release volumes given typical safety measures implemented during operation. In the event of a surface release of an HF product or chemical, any spills at the well site will be contained using standard control measures, such as containment berms, sand, sorbent materials, etc. Such measures would prevent the migration of the product or chemical away from the well site, thereby greatly minimizing the likelihood of exposure to the public.

Beyond these measures, an extra margin of safety can be provided through the selection of chemicals used during the hydraulic fracturing process. HF additives serve many functions and are needed to ensure that the HF job is effective and efficient -- from limiting the growth of bacteria to preventing corrosion of the well casing. The additives used in a typical HF operation depend on the geologic conditions of the formation being fractured. However Halliburton has the ability to provide options to its operators regarding the chemicals to be used. For example, Halliburton has developed CleanStimAUS, a fracturing fluid system made entirely of ingredients sourced from the food industry that provides exceptional fracturing and environmental performance as compared to traditional formulations.

In addition, Halliburton provides a basis upon which to take hazards into account in the selection of chemicals through the use of its Chemistry Scoring Index (CSI). CSI allows Halliburton to assess the relative health, safety and environmental hazards associated with the products it uses in its HF and other operations. By assessing the intrinsic health, safety and environmental hazards of the chemicals in a product and considering the concentrations of those chemicals in the product, the CSI can be used to generate a score for a product that can then be compared to the scores for similar types of products (i.e., the score for a surfactant can be compared to the scores for other surfactants). Thus, through the use of the CSI operators can take hazards into account in selecting the additives to be used in an HF operation (even though under normal use conditions members of the public would not be exposed to any of the products). With the aid of this tool, Halliburton has introduced a number of products that have lower CSI scores for potential use under a variety of conditions.

(f) disposal and treatment of waste water and drilling muds;

Halliburton supports the efforts of operators to recycle and reuse oil and gas wastewater and refers to APPEA's comments for further discussion of operator practices with respect to this issue.

Halliburton encourages the recycling of wastewater by its operators and has developed innovative technologies to support reuse and recycling efforts. For example, Halliburton has developed CleanWave®, a water treatment system that treats wastewater at the well site to enable recycling and reuse of the wastewater for drilling and fracturing subsequent wells. CleanWave treated over 31 million gallons of water in 2012, resulting in an equivalent reduction in the amount of fresh water used in fluid systems. The recycling and reuse of wastewater kept approximately 5,680 truckloads of water off of roads. Halliburton has also developed UniStim, a high performance HF fluid that is tolerant of high concentrations of total dissolved solids, including contaminants consistent with heavy produced water brines. This tolerance facilitates recycling because it allows significantly greater use of minimally treated oilfield produced and flowback water, thereby reducing demands on fresh water and the associated need for truck transportation and disposal.

(g) fugitive emissions;

Halliburton supports the efforts of operators to reduce and/or eliminate fugitive emissions from the well pad.

(h) noise;

Halliburton is aware of local noise ordinances and conducts its operations with these requirements in mind. For further discussion of this issue, we refer you to APPEA's comments.

(i) monitoring requirements;

Similar to well design and installation, the HF process is carefully planned and monitored to ensure that the induced fractures are contained within the target formation to the extent possible, and if there are any indications of abnormal conditions (*e.g.*, abnormal pressure drop), immediate actions can be taken to halt the HF operation. The required HF treatment (*e.g.*, the fracturing pressure, the additive mix and sequencing, duration) is designed by experts. In some cases, these experts will utilize state of the art computer models to ensure that the HF treatment being applied is appropriate for the job and results in fractures that are contained within the target zone. In other cases, experts may rely on prior experience in hydraulically fracturing other wells in the area, the designs for which may have been based in part in models. In addition, a "mini-frac" treatment, utilizing a small volume of HF fluid, may be initially conducted to collect diagnostic data, which are then used to refine the prior computer modeling results and to finalize the HF execution plan.

Data are continuously collected during hydraulic fracturing to monitor operating conditions and to ensure that fractures are propagating in the subsurface consistent with the design. For example, pressure data are collected at several key locations: the pump, wellhead, and intermediate casing annulus (if the intermediate casing has not been cemented to the surface). Typically, pressure variations are minimal and only slight adjustments are required during the HF process. Unusual pressure changes during an HF operation are typically a sign of a problem (such as a surface spill). In such cases, pumping operations are immediately shut down. In addition to pressure monitoring, pressure relief mechanisms are also included in the production wells. For example, API recommends that the intermediate casing annulus should be equipped with a pressure relief valve, with the line from such a valve leading to a lined pit. Such a pressure relief mechanism ensures that if there is a leak from the production casing, any released fracturing fluid is contained within the intermediate casing annulus, and removed before it migrates into the subsurface.

Halliburton has developed a menu of tools to support these monitoring efforts that are available for well operators' use. These include microseismic monitoring and Halliburton Foray fracture analysis. Halliburton's microseismic monitoring, or microseismic fracture mapping, provides an image of the fractures by detecting microseisms or micro-earthquakes that are triggered by shear slippage on bedding planes or natural fractures adjacent to the hydraulic fracture. The location of the microseismic events is obtained using a downhole receiver array that is positioned at the depth of the fracture in an offset wellbore. Microseismic fracture mapping helps assure that the fracture stays in the intended zone and minimizes the number of wells and fractures required.

Halliburton Foray fracture analysis services as a part of the Knoesis℠ Design and Analysis Services can show an operator where and when fractures are propagating. Using highly sophisticated mathematics, Foray turns events in a microseismic cloud into fracture planes. The software then displays those planes to show the dimensions and principal directions of the fractures to reveal the complexity of the fracture network in a specific formation. This helps prevent over-treatment that could waste fluid and proppant. The information also proves useful in optimizing the number and spacing of stages when fracturing. By better understanding how the formation responds, Halliburton can improve the next stimulation design.

The Schedule of Requirements prescribes minimum monitoring during drilling operations. This includes mud monitoring equipment to determine the concentration of gas in the drilling mud, penetration rate and formation pressure monitoring to warn against possible and approaching pressure increases and well performance monitoring. There are also a range of regulatory reporting requirements, from daily drilling reports to incident, injury and emergency notifications.

(j) the use of single or multiple well pads;

Please see section E. 4. for information on the use of single or multiple well pads.

(k) rehabilitation and closure of wells (exploratory and production) including issues associated with corrosion and long term post closure;

Rehabilitation and closure of wells is the responsibility of the operators. As APPEA notes in its submission, the cements used in well construction are specially formulated to withstand high pressures and last for decades. As discussed above, to the extent there are any issues with the integrity of the cement over the long term, any failure of the cement (if it occurs) is not likely to create a pathway for migration of fracturing fluid up the well annulus to shallow depths.

(l) **site rehabilitation for areas where hydraulic fracturing activities have occurred.**

Site rehabilitation is the responsibility of the operators.