CSIRO
Submission #450

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31 August 2017

The Hon Justice Rachel Pepper
Chair, Scientific Inquiry into Hydraulic Fracturing
Hydraulic Fracturing Taskforce
GPO Box 4396 Darwin NT 0801
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Dear Justice Pepper

Thank you for your letters dated 31 July 2017, 14 August 2017 and 18 August 2017 regarding the Hydraulic Fracturing Inquiry Information Requests.

CSIRO's responses to the three information requests are attached. Should you wish to discuss any aspect of this information please contact myself or [redacted] on [redacted] or email [redacted]

Yours sincerely

Dr Damian Barrett
Research Director – Onshore Gas
CSIRO
email [redacted]

Attachments
Attachment 1 Response to Information Request of 31 July 2017
Attachment 2 Response to Information Request of 14 August 2017
Attachment 3 Response to Information Request of 18 August 2017

ATTACHMENT 1

CSIRO RESPONSE TO INFORMATION REQUEST OF 31 JULY 2017

As background context for our response, we would like to provide the following information about methane emissions from unconventional gas resources.

Overview of atmospheric methane concentration and emissions

Mean concentrations of methane in "clean" background air in the southern hemisphere are currently about 1800 ppb (parts per billion mole fraction of methane in dry air) with a seasonal variation of +/- 25 ppb (CSIRO GASLAB data[1]). In regions containing methane sources to the atmosphere, concentrations are more variable and can increase to a few times background levels, due to the source emissions and variable rates of dispersion.

Methane is a greenhouse gas, with a global warming potential of at least 25 times that of carbon dioxide over a 100-year period (IPCC, 2013). Atmospheric methane concentrations have increased by around 1000 ppb since 1750, and are estimated to be responsible for about 17% of the radiative forcing of climate (warming effect) due to all greenhouse gas changes since that time (Meinshausen *et al.*, 2017). About 60% of current global methane emissions are due to anthropogenic sources of which about one third are related to fossil fuel use (Saunois *et al.*, 2016), although large uncertainties remain in these estimates because of the difficulty in measuring the usually diffuse sources of methane emissions (Saunois *et al.*, 2016; Schaefer *et al.*, 2016). The methane concentration in air measured by CSIRO at Cape Grim, Tasmania has grown by between 0.1 and 0.8 % per year over the past decade (CSIRO GASLAB data[2]).

Methane emissions from unconventional gas resources

The use of natural gas in modern, combined cycle gas fired power plants to produce electricity produces lower greenhouse gas emissions than coal fired power stations. However, methane emissions throughout the life-cycle of gas extraction, transportation and usage may reduce the greenhouse gas advantage that natural gas has over coal. Estimates vary on the amount of methane emissions that would negate the advantage that natural gas has over coal, with current literature showing that gas holds this advantage when methane emissions are below around 3 to 4% of the total gas produced (e.g. Alvarez *et al.*, 2012; Lenox and Kaplan, 2016; Littlefield *et al.*, 2016; Qin *et al.*, 2017).

Schwietzke et al (2016) estimate that global methane emissions from natural gas as a fraction of total production is approximately 2%, having declined from 8% over the past three decades. Methane emissions can occur across the life-cycle and include losses through venting or flaring of gas[3]; intentional releases during certain activities such as well completions, well flowback and operation of pneumatic equipment; and unintentional releases (leaks) from infrastructure including pipelines and their fittings (Littlefield *et al.*, 2016).

Measurement of methane emissions can be achieved using a 'bottom-up' approach, which directly measures methane fluxes from individual sources such as wells, compressors, pipelines, and other infrastructure, or using a 'top-down' approach that determines total emissions across an area, such as an entire gas field. A combination of both approaches is likely to be necessary to fully account for all methane emissions from a gas development.

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[1] http://www.csiro.au/greenhouse-gases/

[2] *ibid.*

[3] Flares burn methane to produce carbon dioxide and water, however a small amount of unburnt methane will pass through a flare.

Responses to Information Request

The Panel has formed a preliminary view that, if the industry is given approval to proceed, the following mechanisms will be required to minimise greenhouse gas emissions, and in particular, methane emissions:

- ***implementation of leading practice standards for emission reduction, such as the United States Environmental Protection Agency's New Source Performance Standards, Permitting Rules for the Oil and Natural Gas Industry;***
- ***baseline measurements of methane levels prior to development; and***
- ***ongoing monitoring of methane levels at key points during exploration, development and production.***

The Inquiry invites comments on the above.

CSIRO research recognises global warming caused by anthropogenic greenhouse gases. CSIRO undertakes a broad range of research activities that aim to reduce emissions from Australian industry. The Inquiry's preliminary view that greenhouse gas emissions should be minimised is consistent with CSIRO's research activities.

Improved practices for use in the natural gas sector have arguably reduced methane emissions as a percentage of total production over the last three decades (Schwietzke *et al.*, 2016). Cook *et al.* (2013) also argue that encouraging the use of best practice methods throughout a shale gas industry, such as reduced emissions completions, is likely to mitigate methane emissions. The implementation of appropriate standards, adapted to Australian conditions, are likely to reduce the greenhouse gas footprint of shale gas development.

It is preferable to obtain baseline measurements of methane level prior to development as this is the simplest approach to determining cause and attribution of variation in emissions; however, baseline methane values may still be obtained after development has begun by developing sampling strategies that carefully pair locations with and without gas development, using isotope sampling methods for methane measurement and/or examining trajectories of methane emissions through time. Baseline measurements are also important in establishing closure criteria at the end of a shale gas project's life. We discuss baseline measurements further in our response to point (1) below.

The requirement for ongoing monitoring of methane levels is discussed in our response to point (2) below.

In addition, to the extent possible, please comment on:

1. ***the technologies that are currently available to obtain baseline measurements of emissions, including the possible use of drones;***

Methane concentrations are usually what are measured in the atmosphere while fluxes (or emission rates, and their locations) are usually what are required. Concentrations can vary widely as a result of atmospheric dispersion and changes in the emission rate of various sources. Small differences in concentrations (as little as 1% or less relative – around 20 ppb[4] absolute) across a region can indicate that sources[5] exist within that region. Methane measurements must therefore be precise, at a sensitivity that allows measurement at atmospheric levels and exactly calibrated for these purposes. To infer emissions from concentration (which is usually referred to as the 'inverse problem' in atmospheric physics) requires understanding of the meteorology governing dispersion and necessitates the application of sophisticated numerical models. Further discussion of inversion is presented in our response to point (2) below.

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[4] Parts per billion

[5] Sources may be natural, including from the decomposition of organic matter or natural seepage of gas from the ground, or associated with human activities including from enteric fermentation in livestock, waste disposal and waste water treatment facilities.

An alternative approach is to use tracer gases. For this, a stable gas unrelated to the source is released at a known rate, from the same location as the methane source. Simultaneous downwind concentration measurements of both the tracer, and methane, are made and the emission rate of methane can be calculated as the ratio of the methane and tracer concentrations multiplied by the tracer rate (Day *et al.*, 2015).

The state of the art sensor technologies that are currently commercially available with the detection limits and sensitivities to detect and quantify methane concentrations levels typical of unconventional gas fields are the Picarro Inc Methane/Trace Gas Analyzers[6] and the Los Gatos Research (LGR) Methane Analyzers[7]. They have sensitivities in the order of 1 ppb and are now deployed routinely for emissions monitoring. These analysers are deployed in stationary monitoring systems, driven in a vehicle across the landscape, or mounted in aircraft to continuously measure ambient methane concentrations. The advantages of these sensor technologies are that they are proven technologies, have a fairly high level of reliability and have achieved sufficient sensitivities and detection limits for the purpose of measuring diffuse emissions. The drawbacks of these sensor technologies are their high costs, fairly large infrastructure that are associated with them, high power consumption and total weight, and, high level of technical knowledge required to use and interpret the data from these instruments to obtain quantitative information. LGR has made attempts to address the cost, weight and power issues with their new range of instruments.

In addition to off the shelf sensor technologies, there has been significant recent research and development in miniaturisation, improving detection accuracies, simultaneous detection of multiple gasses and autonomous sensor technologies driven largely by the onshore/unconventional gas industries and environmental concerns in the USA[8]. Such advances are likely to lower costs and allow more sensors to be deployed across the landscape, enabling more accurate information to be obtained and better understanding of emissions with more spatially comprehensive and continuous measurements. Further discussions on the potential use of such systems are provided in our response to point 2.

Airborne monitoring of methane emissions provides means of conducting top-down measurements across a large area, such as a gas field (e.g. Caulton *et al.*, 2014). The use of drones[9] or remotely piloted aircraft systems (RPAS) have been used for aerial mapping, surveying and monitoring in a range of applications. RPAS are being trialled in the Queensland coal seam gas industry for monitoring infrastructure through an Advance Queensland funded project. Partners in this program include Shell's QGC project, the Boeing Company, Boeing subsidiary InSitu Pacific, Telstra and locally based small to medium-sized enterprises providing industry and technical expertise[10].

It is important to note that RPAS are vehicles from which sensors are mounted to enable collection of data. Therefore, the appropriate sensor with the necessary capabilities (low detection limit, high sensitivities, stable calibration and reliable in an airborne environment) is crucial as it the essential component that provides the environmental data. Sensors such as the Picarro Inc and LGR Methane Analyzers have also now been adapted so that they are able to be deployed from an airborne platform (Turnbull *et al.*, 2011; O'Shea *et al.*, 2013; Caulton *et al.*, 2014). With the rapid development of RPAS technology, it is a natural progression to deploy the Picarro Inc or LGR Methane Analyzer on these platforms. Such measurements

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[6] http://www.picarro.com/products_solutions/trace_gas_analyzers/co_co2_ch4_h2o

[7] http://www.lgrinc.com/

[8] https://arpa-e.energy.gov/?q=programs/monitor

[9] "Drone" is a commonly used term that covers a range of unmanned. The Civil Aviation Safety Authority refers to these aircraft as remotely piloted aircraft systems (RPAS). As the name suggests, RPAS are remotely piloted with a human pilot in command and able to manage the flight. RPAS range in size from a few hundred grams to hundreds of kilograms. There are regulatory requirements based on weight of the aircraft and special approval is required to operate a RPAS beyond line of sight. Fully autonomous aircraft that can fly themselves currently require a human pilot to be managing the flight, or case by case approval from CASA. The operation of RPAS and fully autonomous aircraft in Australia and elsewhere in the world are the subject of ongoing research and regulatory reform.

[10] http://advance.qld.gov.au/whats-happening/news/boeing-announcement.aspx

may be useful where a leak has been detected and further characterisation and quantification of the leak is required. Day *et al.* (2017) shows a proof of concept of the coupling of sensors with RPAS.

Another approach to measuring atmospheric methane on a broad geographic scale is through remote sensing[11]. Currently, the sensor technologies that can meet the requirements of low detection limits and high sensitivities for baseline studies are Differential Absorption Lidars (DIAL) or laser systems. These systems were developed historically to monitor leakages in gas pipelines (Fix *et al.*, 2004). Generally, off the shelf DIAL and laser systems only provide point or profile coverage which is appropriate for its historical application where profiles along known locations of pipelines is sufficient. However, for baseline studies the sources and locations of emissions may be unknown and greater spatial coverage is important. Recent advances in this area include the Ball Aerospace Methane Mapper[12]and early trials of this technology have shown that it can provide high spatial resolution coverage, and the ability to detect low levels with high sensitivities. Such systems are currently the most promising to provide baseline measurements. Other remote sensing systems that have been used recently to map methane include NASA's AVIRIS-NG instrument which was deployed across an accidental leak (20,000 kt CH4/hr) in Aliso Canyon (Thompson *et al.*, 2016). The sensitivity of such sensor technologies mean that while they will be able to detect "super emitters," they will have limited application for baseline measurement applications.

In summary, there are a range of off the shelf technologies that are currently deployable as well as some emerging technologies that merit further investigation. However, no single sensor technology alone will provide the data necessary to provide a comprehensive baseline. A combination of top-down and bottom-up approaches using a range of sensor technologies are likely to be required to fully characterise baseline emissions from a region. A comprehensive approach would likely involve:

- remote sensing (such as DIAL sensors) from high altitude aircraft or satellites to provide spatially comprehensive methane concentration maps and to detect and locate emissions sources
- land or aircraft (piloted or RPAS) based methane analysers to characterise detected sources,
- a network of high sensitivity, stable and robust sensors deployed at fixed locations across the landscape to capture temporal variation, including seasonal changes

The methane concentration data obtained by these different technologies would then need to be coupled with observations of meteorological conditions in atmospheric modelling to obtain a picture of methane emissions across the region of interest.

Baseline monitoring of a region identified for future gas development conducted for at least a year before activity begins will help to characterise variations of existing sources, including any seasonal variations. This duration of monitoring would also allow for suitable data to accumulate which can then be used along with post-activity measurements to infer source emissions related to the activity.

2. ***the scope, including the location, of any emissions monitoring that should occur during the exploration, development and production phases, such as, for example, wellheads during completion, liquids unloading, compressor seals and gathering stations;***

The oil and gas sector is already required to report on emissions in accordance with the National Greenhouse and Energy Reporting (NGER) Scheme[13]. The NGER requires corporations that meet the NGER threshold to report all greenhouse gas emissions, energy production and energy consumption from their facilities on an annual basis. The NGER's technical guidelines (Department of the Environment and Energy, 2016) set out requirements for reporting and how emissions should be estimated. For petroleum and gas developments, the guidelines refer to the American Petroleum Institute's compendium of greenhouse gas emissions (API, 2009) in many instances to describe how greenhouse gas emissions should be determined.

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[11] Although technically sensors deployed on an RPAS is a form of remote sensing, here remote sensing refers to sensors on satellites or aircraft flying at high altitude.

[12] http://sine.ni.com/cs/app/doc/p/id/cs-17379#

[13] http://www.cleanenergyregulator.gov.au/NGER

CSIRO has conducted a significant amount of research on greenhouse gas emissions related to the NGER and related reporting requirements (e.g. Mark *et al.*, 2001; Saghafi *et al.*, 2008; Day *et al.*, 2011, 2014; Stuart J. Day, Etheridge, *et al.*, 2017). The NGER allows for the use of a combination of emissions factors[14] and direct measurement of emissions depending on their type and source. Direct measurements can be conducted on a representative sample of sources or across the entire field. The NGER covers the full life-cycle of petroleum and gas development and places emissions in one of three categories:

- flaring – emissions that occur when natural gas is flared. These emissions will include carbon dioxide and the small portion of methane that does not combust as it passes through the flare,
- venting – emissions that occur when natural gas is deliberately vented. These emissions will primarily be methane,
- fugitive – emissions that occur unintentionally, and are also described as leaks. These emissions will primarily be methane.

The direct monitoring of all emissions throughout the life-cycle of shale gas development is a difficult task, as evidenced by the NGER's reliance on emissions factors for many types of emissions. Bottom-up measurements of every emission source is likely to be impractical, instead a combination of bottom-up and top-down approaches as outline in our response to point (1) are likely to be required. We expand on this approach below.

Bottom-up measurements of methane and other greenhouse gas emissions from vents and flares is possible using relatively simple flowmeters and sensors. These measurements are aided by the high concentrations of gases, eliminating the need for high sensitivity sensors, and the fact that the locations of these sources are known.

Bottom-up measurement of fugitive emissions of all leaks are more challenging because the location may not be known and the concentrations of gases released may be low. These leaks would normally be detected during leak detection and repair regimes, which are currently practised by most gas production companies. Note, however, that most leak detection programs do not measure emission rates – the purpose of these inspection is to ensure safe operation of equipment.

To accurately measure all fugitive emissions, monitoring may be required over a range of horizontal scales, from discrete localised sources to area sources. Point sources such as wells and valves (scales of about 1 metre) can be measured directly for their emission rate using standard small portable devices (i.e. flux chambers), or inferred from concentration measurements nearby the source and a simple plume dispersion calculation. Various bottom up methods have been applied to quantifying emission rates at Australian coal seam gas operations. Day *et al.* (2013, 2015) describe methods for measuring coal seam gas emissions. Emissions from coal seam gas wells in Queensland and NSW have been successfully measured using downwind plume traverses and tracer gas techniques (Day *et al.*, 2014, Day *et al.*, 2016; Day *et al.*, 2017).

It can be impractical to obtain measurements of all possible sources and their trends over time if they are distributed across a wide area. Estimation of net emissions from areas up to the regional scale (100 km) can be done using a top-down approach, with automated instruments combined with inverse modelling utilising concentration and meteorological data (Etheridge *et al.*, 2001; Luhar *et al.*, 2014; Day *et al.*, 2017). CSIRO is currently applying these methods in the Surat Basin, Queensland (Etheridge *et al.*, 2001; Day *et al.*, 2013, 2015). Regional scale monitoring may not require prior information on source location and may include emissions from sources previously undetected. Monitoring stations are typically installed across the potential emission area of interest to quantify concentration differences between the background air

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[14] An emissions factor relates the amount of greenhouse gas released to the atmosphere with the activity that causes it to be released and is usually expressed as a weight of greenhouse gas divided by a unit weight, volume, distance or duration of the activity. For gas production, and emissions factor could be expressed as tonnes of methane released per well completion, or tonnes of methane released per tonne of methane produced (for infrastructure such as a pipeline).

upwind of the sources and the downwind perturbed air carrying the source signal. It is preferable to install monitoring stations for several dominant wind directions. Locating stations for regional monitoring is usually best done using atmospheric model simulations of the region with scenarios of likely sources (Day *et al.*, 2015). Typical monitoring stations are described in Berko *et al.* (2014) and Etheridge *et al.* (2016).

Uncertainties in the quantification of both point and area emissions techniques can be significant. Point emissions are usually estimated from measurements of a finite sample (in both duration and space) which may be relatively small compared to the total number of potential point sources across a gas region (e.g. Day *et al.*, 2014). Point emissions can vary over time and it is unlikely that all potential point sources can be located across a natural gas production area. On the other hand, emissions across a large area inferred from inversion of concentration data can be subject to model error and to emissions outside of the monitored domain (the “background”). More frequent and greater density surveys of point sources and a greater number of ground monitoring stations (with suitable precision and inter calibration) across the area of interest for regional monitoring reduces the uncertainties of each technique.

An intermediate scale of emissions monitoring is possible using the eddy-covariance (EC) technique (Leuning *et al.*, 2008) which measures continuous fluxes over an upwind “footprint” of up to about 1 km. The EC technique uses a tower typically 5 to 10 metres tall instrumented with high frequency concentration and micrometeorological instruments. EC has mainly been used for carbon dioxide fluxes but instruments are now available for methane. A high level of instrument and data analysis expertise is usually required. EC monitoring is best applied when there is prior knowledge that sources exist within a small area.

A range of atmospheric methods is available to quantify land to atmosphere emissions of gases across the scales of interest. Leuning *et al.* (2008) presents many of these for application to monitoring geological storage of carbon dioxide. Similar methods would apply to methane and in many cases may be more suitable than for carbon dioxide due to the larger signal-noise of methane in the atmosphere. Application of several methods for monitoring carbon dioxide and methane emissions at a field test site is given by Loh *et al.,* (2009). Luhar *et al.* (2014) used inverse modelling of data from two monitoring stations to locate and quantify carbon dioxide and methane emissions from a point source within an area of about 1 km^2. Atmospheric methods for measuring coal seam gas emissions are outlined by Day *et al.* (2013, 2015). Monitoring of coal mine emissions using mobile platforms, tracer measurements and inverse modelling of data from one monitoring station in the Bowen Basin (Queensland) is presented by Day *et al.* (2017). Preliminary results using regional inverse modelling of concentration data from two stations across the Surat Basin (Queensland) are given by Etheridge *et al.* (2001).

Methane can be emitted from a number of source types in addition to emissions from the natural gas industry. Discriminating the methane in the atmosphere that originated from industrial natural gas from other methane source types can in some cases be assisted with the use of tracers, including gases (e.g. Petron *et al.*, 2012) or isotopes (e.g. Loh *et al.*, 2009; Zazzeri *et al.*, 2015) that naturally accompany the natural gas methane[15], or introduced trace gases such as acetylene (Day *et al.*, 2016).

Monitoring ideally would occur throughout the life of the gas well from exploration to provide baseline beyond the closure to determine progress towards closure criteria. Because of the wide area that would need to be covered and other overlapping influences, spatially comprehensive (further than just the gas infrastructure) and continuous monitoring with a combination of sensor technologies as described above would be ideal. Wide scale (or top-down) monitoring may include remote sensing methodologies or ground based monitoring such as the baseline monitoring system currently being developed by the CSIRO in the Surat Basin coal seam gas field in Queensland (Etheridge *et al.*, 2001; Day *et al.*, 2013, 2015).

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[15] Natural gas produced from shale gas resources is likely to be thermogenic in origin (created by thermal conversion of organic matter), and is likely to have components such as ethane, propane and volatile organic compounds associated with it. Biological sources of gas, including most coal seam gas resources, will not have these other components and will also have a different isotopic signature to thermogenic gas.

3. ***the use of emission limits that, if exceeded, would trigger an investigation, make-good requirements and/or a penalty;***

The use of emission limits will depend on the policy objectives that regulation is trying to achieve, and the practicality of measuring emissions at various scales or sources. CSIRO is not in a position to comment on matters of government policy, however we can make the following observations:

- As outlined in our response to point (2) above, the detection and quantification of emissions from a single source or leak is likely to be difficult.
- The use of natural gas in modern, combined cycle gas fired power plants to produce electricity produces lower greenhouse gas emissions than the use of coal fired power stations. However, methane emissions throughout the life-cycle of gas extraction, transportation and usage may reduce the greenhouse gas advantage that natural gas has over coal. Estimates vary on the amount of methane emissions that would negate the advantage that natural gas has over coal, with current literature showing that gas holds this advantage when methane emissions are below around 3 to 4% of the total gas produced (e.g. Alvarez *et al.*, 2012; Lenox and Kaplan, 2016; Littlefield *et al.*, 2016; Qin *et al.*, 2017).
- The global average methane emissions from gas production is currently estimated to be 2% of the total gas produced (Schwietzke *et al.*, 2016).
- A carbon price, if implemented, would likely place a cost on methane emissions.

4. ***the need for transparency when setting emission limits; and***
5. ***whether or not baseline measurements and on-going monitoring should be undertaken by an independent body.***

The following response considers issues raised in points (4) and (5) together. CSIRO's research through the Gas Industry Social and Environmental Research Alliance (GISERA – www.gisera.org.au) has consistently found that trust[16] is a key issue for stakeholders (Leonard, McCrea and Walton, 2016; Walton, Mccrea and Leonard, 2016; Walton *et al.*, 2017). Transparency is important in establishing trust and this will apply to the setting of emission limits, as with other aspects of regulation (Dietz and Stern, 2007). The validity and defensibility of research used in setting emission limits will be important in establishing the community's trust.

The community's trust will also be important for the collection of baseline measurements and ongoing monitoring of methane emissions should a shale gas industry develop. There are several aspects that could influence trust in the collection of these data (Dietz and Stern, 2007; Leonard, McCrea and Walton, 2016), including:

- The technical credibility of the organisation collecting the data. Monitoring of methane concentrations at the locations and scales described in our response to points (1) and (2) above can be carried out by many experienced operators using modern off the shelf instruments configured for the task and its environment. However, achieving the precision and absolute accuracy of concentrations required to infer sources, and undertaking the plume dispersion and inverse modelling of sources, are specialised tasks that few agencies are capable of. Inverse modelling of sources across the scale relevant to a natural gas basin is a research task still undergoing development. This technical credibility would also need to be presented in such a way that it could be assessed all stakeholders.

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[16] In this context, we mean trust within the community, towards government and CSG companies.

- The level and type of oversight given to the collection of measurements, regardless of the organisation collecting the data. Integrating community perspectives and values into decision making will be important to underpin trust
- The source of funding to the organisation collecting the data
- The availability and transparency of the data
- The provision of decision-relevant information including explicitness about assumptions and uncertainties

These trust issues are not unique to methane emissions measurement, but apply to the management and monitoring of other potential impacts from shale gas development (North *et al.*, 2014).

Comments on section 9.8 of the interim report.

The findings of the Preliminary Assessment that "… *methane emissions dominate the upstream GHG emissions*" and that "… *the quantity of methane emissions is more uncertain and they are more amenable to reduction*" are well supported. The US Environmental Protection Agency's Natural Gas STAR Program also recognises these points and encourages industry to adopt practices to reduce or eliminate atmospheric emissions of methane (US Environmental Protection Agency, 2016).

Table 9.2 appears to cover the main hazards in preventing lower levels of methane emission performance from being achieved. The inquiry may like to consider:

- Amending the hazard in row one of the table, or adding new hazard, to include regulations that restrict the development of technologies that lower emissions.
- Amending the hazard in row four of the table to include the possibility of inadequate monitoring of both baseline emissions and emissions during production.

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