To the inquiry:

1) I would like to call to the attention of the Inquiry two recent research reports into methane emissions associated with unconventional oil and gas extraction from the University of Melbourne Energy Institute entitled:

"A review of current and future methane emissions from Australian unconventional oil and gas production"

http://climate-energy-college.org/review-current-and-future-methane-emissions-australianunconventional-oil-and-gas-production

"The risk of migratory methane emissions resulting from the development of Queensland coal seam gas"

http://www.tai.org.au/sites/defualt/files/P320%20Migratory%20emissions%20FINAL_0.pdf

Methane is a powerful greenhouse gas. These two research reports highlight (amongst many other things) that:

"Despite Australian Government greenhouse-gas reporting requirements having been established in 2009 and Australia's unconventional gas industry operating at significant scale since 2010 and rapidly expanding since, there has as yet been no comprehensive, rigorous, independently- verifiable audit of gas emissions. Indeed, to quote CSIRO, "reliable measurements on Australian oil and gas production facilities are yet to be made."

"In the United States [...] emissions ranging from 2 to 17% have been reported."

"If methane emissions from unconventional oil and gas production are being significantly underreported, this could have a large impact on Australia's national greenhouse accounts."

Those reports indicate and recommend that a significant research effort must be done before it is known the full extent to which methane emissions occur as a result of unconventional oil and gas extraction.

2) I would like to call to the attention of the Inquiry the new report (attached as a pdf) entitled:

"Infrared video-recording methane emissions in the Queensland coal seam gas fields"

This report documents the use of a state-of-the-art industrial infrared camera to detect and visualise methane emissions occurring in the Queensland coal seam gas fields.

This report also highlights the use in the United States of sophisticated air-borne infrared methane detection and quantification equipment (NASA et al.).

This report highlights that significant methane emissions do occur as a result of unconventional gas

extraction and that further field-work is needed to understand and quantify methane emissions in Australian oil and gas fields.

3) As author or co-author of two of the above reports, and with 35 years of experience as an engineer and manager in the oil and gas industry, I would be happy to brief the inquiry on what is known about methane emissions from unconventional gas and oil extraction.

Regards,

Tim Forcey Energy Advisor, formerly with the University of Melbourne Energy Institute Sandringham, Victoria

INFRARED VIDEO-RECORDING METHANE EMISSIONS IN THE QUEENSLAND COAL SEAM GAS FIELDS FEBRUARY 2017







Tim Forcey Independent Energy Advisor



forcey5@optusnet.com.au

Table of Contents

1. EXECUTIVE SUMMARY	3
Continuous methane releases made visible with infrared-sensing camera	4
Intermittent methane emissions visualised with infrared	5
Migratory emissions? The bubbling Condamine River and Wambo Creek	6
U.S. CSG fields: Airborne-infrared technologies quantify emissions	8
Evidence should not be ignored, and other recommendations	9
2. ABOUT THE AUTHOR	11
3. ACKNOWLEDGEMENTS	11
4. BACKGROUND: WHY ARE CSG INDUSTRY METHANE EMISSIONS	
IGNORED?	12
5. INFRARED METHANE-IMAGING TECHNOLOGY	16
Infrared imaging of Aliso Canyon, California gas storage facility well blowout	18
Community use of the FLIR GF-320 in North America: Earthworks Action	18
Australian community use of FLIR GF-320 inhibited by high cost	19
Quantifying methane emissions	19
6. QUEENSLAND CSG: VIDEO-RECORDING METHANE EMISSIONS	20
Continuous methane releases	20
Intermittent methane releases	22
Methane bubbling from the Condamine River	24
Wambo Creek bubbling	27
7. U.S.: AIRBORNE INFRARED QUANTIFIES METHANE EMISSIONS	29
8. RECOMMENDATIONS AND FURTHER WORK	33
9. BIBLIOGRAPHY	35

1. EXECUTIVE SUMMARY

Australia's coal seam gas (CSG) industry is large and expanding. Over \$A 80 billion has been spent to extract CSG and liquefy it at facilities near Gladstone Queensland.¹ The first exports of liquefied natural gas (LNG) commenced in December 2014.

Over 5,000 CSG wells have been drilled so far. Tens of thousands more are planned. The "before and after" aerial photographs (below) show the placement of more than 150 CSG wellpads in Queensland. The spacing between wellpads is 500 to 700 metres.



"Before and after" aerial photographs showing the placement of more than 150 CSG wells in Queensland. (Google earth)

The main chemical component of coal seam gas (CSG) is methane. Methane is also a powerful greenhouse gas. If just a small fraction of extracted methane is emitted into the Earth's atmosphere, CSG can become the most climate-disrupting form of energy [1].

As a chemical, methane is odourless, colourless, and invisible to the naked eye. Methane is also lighter than air - it quickly disperses when released into the Earth's atmosphere. These characteristics mean that methane released during industry gas-field operations can be readily overlooked, ignored, or hidden.

Methane can, however, be imaged using infrared-sensing equipment.

This report describes our efforts video-recording methane emissions in the Queensland CSG fields using a FLIR GF-320 infrared video camera (pictured below).



Image from www.flir.com

¹ "Heading north, how the export boom is shaking up Australia's gas market" <u>https://theconversation.com/heading-north-how-the-export-boom-is-shaking-up-australias-gas-market-52963</u>T.Forcey

INFRARED VIDEO-RECORDING METHANE EMISSIONS IN THE QUEENSLAND COAL SEAM GAS FIELDS - FEBRUARY 2017

Using the FLIR GF-320 we observed methane being released into the atmosphere via:

- continuous releases from "high-point vents" on water-gathering pipelines
- intermittent releases from other gas field equipment
- methane bubbling from the Condamine River and Wambo Creek.

Continuous methane releases made visible with infrared-sensing camera

The following photographs and video (recorded in February 2017) show methane being continuously released from a high-point vent on a coal-seam-water gathering pipeline in the Queensland CSG fields. The video begins with a visual image of the vent piping and equipment. The FLIR GF-320 camera is then switched to infrared mode (black and white palette). In this mode the vented methane appears as a black plume dispersing in the wind. The FLIR GF-320 camera is then switched back to visual mode at the end of the video.



Visual and infrared images of methane being released from a high-point vent on a coal-seam-water pipeline. (For infrared image, black and white palette selected; methane plume appearing black). Video available at this link: https://vimeo.com/205496570

The above infrared video shows a significant though unquantified amount of methane being emitted from this single high-point vent. Disturbingly, with respect to Australia's national greenhouse-gas reporting to the United Nations, methane emissions from CSG equipment types such as these vents...

"...are, effectively, **assumed to be zero**. This means that the national emissions inventory currently understates emissions for coal seam gas production. The possible amount of the understatement is completely unknown." [1]

Throughout the Australian CSG fields, there are likely to be thousands of high-point vents continuously venting methane. People living in the gas fields have reported methane venting for several years. During our two-day visit to the CSG fields we recorded a number of continuously-emitting vents.

Intermittent methane emissions visualised with infrared

In addition to *continuous* sources of methane emissions such as high-point vents, there are thousands of locations across the Australian CSG fields where large volumes of methane can be *intermittently* released from equipment. Release duration can last from minutes to hours.

Gas producers will intermittently release methane from equipment for the purposes of pressure control and equipment purging. Methane can be discharged from equipment and piping at high velocity, which can result in high sound (noise) levels. If there are people living in the area, these intermittent releases can lead to residents filing noise complaints.

The following video begins with a visual image (with audio) of an intermittent methane release in the Queensland CSG fields. The visual image is then followed by infrared video that allows the emitted methane to be seen.



Video showing intermittent methane releases in the Queensland CSG fields. (Link here: <u>https://vimeo.com/206776003)</u>

As was described in the previous section for continuous emissions, in Australia's national greenhouse accounts reported to the United Nations, intermittent methane emissions from CSG operations are also effectively assumed to be zero.

Migratory emissions? The bubbling Condamine River and Wambo Creek

In addition to examining methane emissions from CSG equipment, we also used the FLIR GF-320 camera to record evidence of methane bubbling from the Condamine River.

Data published by the gas-producing organisation APLNG indicates that the volume of gas discharging from the river quadrupled from 500 litres per minute in September 2013 to nearly 2,000 litres per minute in January 2016 [2]. For comparison, a gas flow of 2,000 litres per minute, if constant over a year, is equivalent to the amount of gas required to supply around 800 traditional Melbourne gas-using homes. That volume of methane is also the greenhouse gas equivalent of 65,000 tonnes per year of carbon dioxide.

APLNG has now placed large "upside-down buckets" on the bottom of the river in order to capture some of this bubbling gas. From the "buckets", APLNG has installed pipelines to take the gas away to a vent and two flares.²

Despite APLNG's efforts to divert methane emissions from the river, methane gas continues to bubble from the river as shown in the following photograph and in visual and infrared video recorded in February 2017. With infrared imaging in the video, methane emissions appear as black fumes and bubbles persisting on the surface of the river.



Photograph of bubbling Condamine River, February 2017. The bulk of the gas is being captured by "upside-down buckets" placed on the river bed with captured gas then piped to onshore vents and flares. Visual and infrared video of methane bubbles here: <u>https://vimeo.com/206778242</u>

² <u>https://www.aplng.com.au/topics/coal-seam-gas/condamine-river-seeps.html</u>

INFRARED VIDEO-RECORDING METHANE EMISSIONS IN THE QUEENSLAND COAL SEAM GAS FIELDS - FEBRUARY 2017

Though lesser in volume than at the Condamine River, we also observed similar bubbles in Wambo Creek, at the Avenue Road crossing. This location is about 10 kilometres from the Condamine River location. The following photograph and video records bubbles from Wambo Creek.



Bubbles emanating from Wambo Creek, Queensland Video available here: <u>https://vimeo.com/206779840</u>

Methane bubbling from the Condamine River and Wambo Creek could be examples of migratory methane emissions. Migratory emissions are defined as where, as a result of unconventional oil and gas development, methane may migrate upward and laterally out of its original reservoir. Migratory methane may eventually reach the Earth's surface and enter the atmosphere at a considerable distance away from the site of original oil and gas drilling or other disturbance [1].

In Australia's national greenhouse accounts reported to the United Nations, migratory emissions from CSG operations are assumed to be zero.

U.S. CSG fields: Airborne-infrared technologies quantify emissions

The FLIR GF-320 camera is not able to measure the amount of methane gas being released from a vent or other release point (e.g. in kilograms per hour). However, using other airborne infrared-sensing equipment, "top-down" methane-emission measurements have been reported in the United States.

Frankenberg et al. [3] used airborne-infrared imaging in the "Four Corners" region of the U.S. to identify 250 individual methane plumes. With the airborne instruments the researchers were able to quantify methane emission rates for every plume. These ranged from two kilograms to 5,000 kilograms per hour.

The Four Corners region is the largest source of coal seam gas in the United States.³ One reason the Four Corners region is of interest is because satellite observations across the entire U.S. indicated a unique "hot-spot": a large volume of methane being emitted into the Earth's atmosphere from this area [4].

The image below shows quantitative results for just one of the 250 methane-emission sources identified: a gas processing plant. With airborne infrared imaging, the researchers measured methane being released at an extremely high rate of five tonnes per hour (120 tonnes per day).



Methane emissions from gas field operations in the "Four Corners" region of the southwestern U.S., quantified by Frankenberg et al. [3].

As listed below, we recommend that the "top-down" methane quantification techniques used by Frankenberg et al. are applied to the current and prospective Australian unconventional oil and gas-producing regions.

³ Oil and gas is also produced by conventional means in this region.

INFRARED VIDEO-RECORDING METHANE EMISSIONS IN THE QUEENSLAND COAL SEAM GAS FIELDS - FEBRUARY 2017

Evidence should not be ignored, and other recommendations

The Australian Government should not ignore the evidence of large methane emissions from CSG operations that has been highlighted by the CSIRO in 2014 and is reinforced by this report.

The potential for large volumes of methane being released from thousands of release points across the CSG fields calls into question the ambitious methane-emission targets set by the CSG-LNG industry in their Environment Impact Statements.

Notably, new proposals such as the Santos plan to develop 850 wells as part of the Narrabri Gas Project, continue to be based on highly questionable emissions factors instead of actual field measurements. In February 2017, Santos released for public review the Environmental Impact Statement (EIS) for this proposed project. In that EIS, Santos continues to use the gas industry's out-dated methane-emission factors [5].

Santos makes no reference to the actual methane-emissions performance that it or other CSG companies have achieved at Queensland CSG operations over the last few years.

Neither the Narrabri CSG project nor any other project should be approved on the basis of inappropriate methane-emission estimates. Rather real-world data now available from years of Queensland CSG operations should be collected, published, reviewed by independent assessors, and used as the basis for project commitments.

Furthermore, the evidence of potentially large and unaccounted-for methane emissions calls into question the accuracy of Australia's internationally-reported greenhouse gas accounts, based as they are on emissions factors that assume very low and even **zero** levels of methane emissions from CSG operations [1].

The University of Melbourne recommended further investigation into methane emissions from Australian CSG fields as listed below [1]:

- In existing and prospective unconventional oil and gas production regions, baselines are established so that the methane-emissions character of a region is known prior to expansion of oil and gas production or deployment of wells and other equipment
- Commitments made by CSG-LNG producing companies in Environmental Impact Statements (EISs) are mandated and confirmed with regular, rigorous, and verifiable audits.
- Factor-based assumptions should be replaced with direct measurement where emissions may be significant.
- The latest-globally-available technologies and techniques are used to detect, quantify, cross-check, and minimise methane emissions
- Priority is given to the implementation of methane-emission-detection techniques that can ensure no 'super-emitters' go undetected."

Regarding developing an understanding of migratory methane emissions, the University of Melbourne researchers also recommended the development of:

"...an integrated geological-hydrological model. This model would assess the implications of formation heterogeneity, irregular formation thickness, coal seam dewatering and depressurisation, and water extraction by all users." [6]

Furthermore, given the remarkable results reported recently by Frankenberg et al. for the "Four Corners" region of the U.S. [3], those techniques should also be applied to Australian CSG regions, both to establish baselines in prospective areas and also to quantify emissions from existing operations. Quantifying methane emissions from the thousands of existing high-point vents should be an area of immediate focus.

INFRARED VIDEO-RECORDING METHANE EMISSIONS IN THE QUEENSLAND COAL SEAM GAS FIELDS - FEBRUARY 2017

2. ABOUT THE AUTHOR

Tim Forcey is a Chemical Engineer with over 35 years of experience in petrochemicals, oil, gas, electricity, and energy efficiency with organisations including ExxonMobil, BHP Billiton, Jemena, and the Australian Energy Market Operator (AEMO), and the University of Melbourne Energy Institute.

With BHP Billiton from 1994 to 2010, Tim held positions including Senior Advisor -Facilities and Operations, with responsibility for the Bass Strait oil and gas joint venture. Tim also led teams responsible for designing and building gas processing plants and LNG facilities.⁴

With Jemena in 2010, Tim was Manager of the Queensland Gas Pipeline during a critical time when its capacity and production was doubled.

With AEMO, Tim held the role of Gas Principal and was responsible for publishing AEMO's major gas industry planning documents including the Gas Statement of Opportunities (GSOO).

More recently as Energy Advisor at the University of Melbourne Energy Institute (MEI), Tim has published leading research reports and articles covering topics such as:

- methane emissions from Australian unconventional oil and gas production [1]
- eastern Australian electricity and gas demand trends [7]
- the economic advantages of gas alternatives such as heat pumps and energy efficiency measures.

Tim has presented MEI research findings to Australian Government Members of Parliament, to New South Wales and Victorian upper house gas-industry inquiries, and to other industry, government, academic, and community stakeholders.

In 2016, Tim chaired part of the Australian Domestic Gas Outlook (ADGO) conference and at that conference also presented on

- the decline of gas consumption in eastern Australia
- the economic advantages of gas alternatives.

Tim is an experienced thermographer who has published and presented information on the use of thermal-imaging to improve the performance of homes and commercial buildings.

3. ACKNOWLEDGEMENTS

This research was supported by the Lock The Gate Alliance, a national grassroots organisation made up of over 40,000 supporters and more than 250 local groups who are concerned about unsafe coal and gas mining.

⁴ Tim's gas-industry publications include "A competitive offshore LNG scheme utilising a gravity base structure and improved nitrogen cycle process", presented at LNG12, 1998.

INFRARED VIDEO-RECORDING METHANE EMISSIONS IN THE QUEENSLAND COAL SEAM GAS FIELDS - FEBRUARY 2017

4. BACKGROUND: WHY ARE CSG INDUSTRY METHANE EMISSIONS IGNORED?

Australia's coal seam gas (CSG) industry is large and expanding. Over \$A 80 billion has been spent to extract CSG and liquefy it at facilities near Gladstone Queensland.⁵ The first exports of liquefied natural gas (LNG) commenced in December 2014.

Over 5,000 CSG wells have been drilled so far. Tens of thousands more are planned. The "before and after" aerial photographs (below) show the placement of more than 150 CSG wellpads in Queensland. The spacing between wellpads is 500 to 700 metres.



"Before and after" photos showing the placement of more than 150 CSG wellpads in Queensland. (Google earth)

The main chemical component of coal seam gas (CSG) is methane. Methane is also a powerful greenhouse gas. If just a small fraction of produced methane is emitted into the Earth's atmosphere, CSG can become the most climate-disrupting form of energy [1].

As a chemical, methane is odourless, colourless, and invisible to the naked eye. Methane is also lighter than air - it quickly disperses when released into the atmosphere. These characteristics mean that methane released into the Earth's atmosphere during CSG operations can be readily overlooked, ignored, or hidden.

Methane can be released into our Earth's atmosphere during all stages of fossil gas production and end-use, as listed in the following table:

⁵ "Heading north, how the export boom is shaking up Australia's gas market" <u>https://theconversation.com/heading-north-how-the-export-boom-is-shaking-up-australias-gas-market-52963</u>T.Forcey
12

INFRARED VIDEO-RECORDING METHANE EMISSIONS IN THE QUEENSLAND COAL SEAM GAS FIELDS - FEBRUARY 2017

Even after a gas reservoir is commercially depleted, methane can continue to flow into the Earth's atmosphere via abandoned wellbores and through rock strata. Movement of methane through rock strata can be known as "migratory methane emissions". These are defined as where, as a result of unconventional oil and gas development, methane may migrate upward and laterally out of its original reservoir. Migratory methane may eventually reach the Earth's surface and enter the atmosphere at a considerable distance away from the site of original oil and gas drilling or other disturbance [1].

To illustrate the potential for high-volume methane releases, in 2014, the CSIRO was tasked with measuring methane from a small sample of 43 wellpads in the CSG fields [8]. (Note, more than 5,000 CSG wells have now been drilled across Queensland and New South Wales.) At 9% of the wellpads investigated (4 out of 43), the CSIRO was unable to measure methane emissions from the selected wellpads because large plumes of methane were drifting across some wellpads and interfering with the CSIRO's measurements. The CSIRO stated that these plumes originated beyond the wellpads from vents, pump seal leaks, and a gas compression plant.

In 2014 the CSIRO concluded this work by writing:

"In addition to wells, there are many other potential emission points throughout the gas production an distribution chain that were not examined in this study. These include well completion activities, gas compression plants, water treatment facilities, pipelines and downstream operations including LNG facilities." "... reliable measurements on Australian oil and gas production facilities are yet to be made." [8]

These coal seam gas emissions are a significant concern because of health risks posed by gas releases [1] and also because methane is a powerful climate-impacting greenhouse gas.

The Australian Government is responsible for reporting an accurate assessment of the nation's greenhouse gas emissions. However as reported in October 2016 by researchers at the University of Melbourne:

"... despite Australian Government greenhouse-gas reporting requirements having been established in 2009 and Australia's unconventional gas industry operating at significant scale since 2010 and rapidly expanding since, there has as yet been no comprehensive, rigorous, independently-verifiable audit of [methane] emissions." [1]

Disturbingly in 2017, gas industry proponents and the Australian Government continue to ignore the findings and recommendations of the CSIRO and the University of Melbourne. Claims are made that methane emissions from the entire CSG-LNG production system are negligible. These claims are based on selecting results *only from wellpads* (ignoring methane emissions from all other aspects of CSG production), and only from *those* wellpads where the CSIRO achieved low methane-emission results (on average).

Gas-industry proponents and the Australian Government continue to ignore the large volume of methane emitted outside of wellpads. The following graphic illustrates how it is a misleading practice to focus only on emissions from wellpads (the red circles shown on the graphic), while ignoring all other sources (yellow-coloured equipment).



Diagram of CSG facilities showing equipment included in, and excluded from, methane-emission estimates [9].

Methane emissions from CSG operations reported by the gas industry to the Australian government and in turn by the Australian government to the United Nations continue to be based on simple assumptions and estimated emission factors (EFs) rather than actual measurements. The factors used are "out-dated and ... lack demonstrated relevance to the Australian unconventional oil and gas industry." [1]

Indeed, in 2016 an expert review team at the United Nations called on Australia to:

"... make efforts to improve the data for the emissions from this category,

including the development of updated EFs that represent production activities in unconventional gas production." [10]

Referring to the United Nations recommendations, the Australian Government identified improvement measures that it "hopes":

"... can lead to the development of more representative EFs." [11]

If Australia is significantly under-reporting methane emissions from the CSG industry, this could jeopardise Australia's ability to meet international climate-change-mitigation commitments [9].

In the Environmental Impact Statements for the three now-operational Queensland CSG-LNG projects, industry proponents committed to limit methane emissions to no more than 0.1% of total gas production. Unfortunately, there is no evidence that these ambitiously-low commitments are being met. Rather, based on gas industry methaneemission figures reported in the United States, raising the CSG-LNG industry methane emission target by a factor of ten (< 1.0% of total gas production) may be a more realistic goal. (Ref [1], Table 4.)

Repeating the main point, no actual methane-emission measurements have yet been published by the Australian CSG industry nor by the Australian Government.

In February 2017, the gas company Santos released, for public review, the Environmental Impact Statement (EIS) for the proposed New South Wales Narrabri CSG project. This proposed project involves 850 CSG wells. In the Narrabri EIS [5], Santos continues to use the gas industry's out-dated and irrelevant methane-emission factors and makes no reference to the actual methane-emissions performance achieved at its Queensland CSG operations.

Providing more detail, the University of Melbourne's review of Australian CSG methane-emission measurement and reporting [1] [6] found:

- "no baseline methane-emission studies were completed prior to the commencement of the Australian CSG-LNG industry
- there is significant uncertainty about methane-emission estimates reported by oil and gas producers to the Australian government, and by the Australian government to the United Nations. The United Nations has requested Australia improve its methodologies.
- Australian methane-emission reporting methodologies rely to a significant extent on assumed emissions factors rather than direct measurement
- the assumptions used to estimate methane emissions include some that are out-dated, and some that lack demonstrated relevance to the Australian unconventional oil and gas industry
- if methane emissions from unconventional oil and gas production are being significantly under-reported, this could have a large impact on Australia's national greenhouse accounts."
- fractures induced by hydraulic fracturing ('fracking') can introduce new [methane] migration pathways beyond the coal measures into overlaying and underlying formations if the fracturing job is poorly executed. This risk maybe enhanced if the surrounding geology is not well understood.
- water bores and coal exploration bores are potential sources of methane emissions and it has been acknowledged that the existence of methane in water bores can be the consequence of gas migration from the coal seams due to depressurisation. Well integrity is an important long-term issue not only

in dedicated oil and gas wells but also in existing bores that were not designed to prevent migratory emissions."

State and federal governments can ignore CSG methane emissions because, for one reason, methane gas is odourless, colourless and invisible. However one way to make this invisible gas visible in the CSG fields is to deploy infrared-sensing technologies such as the FLIR GF-320 infrared video camera (described in Section 5).

5. INFRARED METHANE-IMAGING TECHNOLOGY

This section describes the use of infrared imaging techniques to detect, visualise, and quantify methane emissions.

There has been rapid technological development in the field of methane-emission detection and quantification. One now commercially-available technology is the FLIR GF-320 infrared-sensing video camera.



Image from www.flir.com

As shown on the figure below, certain molecules such as methane (the dominant chemical component of coal seam gas) absorb and re-transmit infrared radiation at certain wavelengths.



The FLIR GF-320 is tuned to detect gases that absorb infrared radiation at a wavelength of 3.3 microns (μ m). Many gaseous chemicals absorb infrared radiation at that wavelength with the FLIR GF-320 able to detect the following hydrocarbons and ketones: ⁶

benzene	butane	ethane	ethylbenzene
ethylene	heptane	hexane	isoprene
MEK	<u>methane</u>	methanol	MIBK
octane	pentane	1-pentene	propane
propylene	toluene	xylene	

According to FLIR, a company that supplies infrared methane-imaging technology:

"The construction of a thermal imaging camera is similar to the construction of a digital video camera. There is a lens, a detector, some electronics to process the signal from the detector and a viewfinder or screen for the user to see the image produced by the camera. The detectors used for the Gas Detection cameras are quantum detectors that require cooling to cryogenic temperatures (around 70K or -203°C). The [GF-320] camera uses an indium antimonide (InSb) detector."

In order to achieve temperatures down to around -200°C in a hand-held video camera, the FLIR GF-320 uses a Stirling cooler working with helium gas refrigeration. When the camera is first turned on, around ten minutes of cool-down time is required before the required low temperature is reached and the camera is then ready to be used. The Stirling cooler runs continuously from them on as long as the camera is turned on. The charge of a single rechargeable battery lasts for around four hours.

Although the user can select different colour palettes with the GF-320, we used the black and white palette with methane emissions appearing as black-coloured clouds, plumes, fumes, or bubbles. Key to obtaining a good image is being able to view the rising blackcoloured gas against a consistent and contrasting temperature background, such as a clear sky.

While recording, the user of the GF-320 has the ability to switch from a visual (colour) image to the infrared image and back to the visual image. Two different lenses are used for the visual and infrared views; therefore during continuous filming the position of the target image will appear to shift or change position as the switch is made from visual to infrared and back again.

The GF-320 will detect temperature differences of surfaces. It will also detect water vapour along with methane (and the other hydrocarbons listed above) at the 3.3 micron wavelength. These characteristics of the camera make it difficult to interpret infrared

⁶ FLIR Gas Detection Guidebook. <u>http://www.flir.com.au</u>

INFRARED VIDEO-RECORDING METHANE EMISSIONS IN THE QUEENSLAND COAL SEAM GAS FIELDS - FEBRUARY 2017

images of hot combustion gases (also known as flue, or exhaust gases) even though these emissions can contain uncombusted methane.

Infrared imaging of Aliso Canyon, California gas storage facility well blowout

In October 2015, a well blew out at the Aliso Canyon, California gas storage facility. Ninety-six thousand tonnes of methane was released over a 111 day period.

A famous use of infrared imaging, shown below, the invisible gas release was made visible.



2015 methane leak made visible with infrared imaging, Aliso Canyon, California. (Earthworks/Reuters)

Community use of the FLIR GF-320 in North America: Earthworks Action

In North America, people from communities living near oil and gas production facilities can access a FLIR GF-320 equipped with a telephoto lens via the organisation Earthworks Action. Recorded videos can then be uploaded to the Earthworks Action Youtube channel.⁷

For example, the video below shows a heavy cloud of hydrocarbons being released from a vent stack in Texas (click on link): <u>https://youtu.be/RAo3mh8CwMU</u>



⁷ <u>https://www.youtube.com/user/earthworksaction/videos</u>

INFRARED VIDEO-RECORDING METHANE EMISSIONS IN THE QUEENSLAND COAL SEAM GAS FIELDS - FEBRUARY 2017

Australian community use of FLIR GF-320 inhibited by high cost

Although both continuous and intermittent methane releases are frequently reported by people living in or near Australian CSG fields, infrared video recordings of methane releases are rare. This is because of the restricted availability and high cost of the FLIR GF-320 camera in Australia: \$A 137,000 to purchase or daily rental cost of \$A 1,700 per day. Another impediment is the cost and lack of technical resources available to the community at short notice.

Quantifying methane emissions

The GF-320 can detect and image a methane plume or release into the atmosphere. However it cannot measure the size of a methane release (e.g. in kilograms or kilograms per hour).

Nevertheless, infrared-imaging technology progress now allows methane-emission rates to be measured.

With a portable device, Galfalk et al. [12] used "optimised infrared hyperspectral imaging", where "a time-averaged methane image can be calculated pixel by pixel" to confirm the flowrate of methane released in three examples: into the atmosphere from their laboratory, emissions from cows housed in a barn, and to methane emanating from a sludge deposit.

"Altogether the presented system and related image analyses were capable of visualizing and quantifying [methane] levels, and in many cases also associated fluxes, from widely different types of sources and under varying conditions."

More directly relevant to Australian CSG operations is the U.S. experience of using airborne-infrared imaging to quantify emissions from the "Four Corners" CSG-producing region [3]. See Section 7 for details of this breakthrough U.S. methane research.

6. QUEENSLAND CSG: VIDEO-RECORDING METHANE **EMISSIONS**

This report section describes our infrared video-recording of continuous and intermittent methane vents and releases in the Queensland CSG fields, as well as methane bubbling from the Condamine River and Wambo Creek.

Our methane investigations were broadcast by the Australian Broadcasting Corporation (ABC) television on 28 February 2017. The six minute video news item is available at this link (page down): http://www.abc.net.au/news/2017-02-28/methane-emissions-fromcoal-seam-gas-climate-change/8310932

Continuous methane releases

From vents and other CSG equipment, methane can be continuously released into the Earth's atmosphere.

The following photographs and video (recorded in February 2017) show methane being continuously released from a high-point vent on a water-gathering pipeline in the Queensland CSG fields. The video begins with a visual image of the vent piping and equipment. The FLIR GF-320 camera is then switched to infrared mode (black and white palette) during which the vented plume of methane appears as a black plume dispersing in the wind. The FLIR GF-320 camera is then switched back to visual mode at the end of the video.



Visual and infrared images of methane being released from a high-point vent on a coal-seam-water pipeline. (For infrared image, black and white palette selected; methane plume appearing black). Video available at this link:

https://vimeo.com/205496570

INFRARED VIDEO-RECORDING METHANE EMISSIONS IN THE QUEENSLAND COAL SEAM GAS FIELDS - FEBRUARY 2017

These images show a significant (though unquantified) amount of methane being emitted from this single high-point vent. Disturbingly, with respect to Australia's national greenhouse-gas reporting accounts, methane emissions from CSG equipment types such as these vents...

"...are, effectively, **assumed to be zero**. This means that the national emissions inventory currently understates emissions for coal seam gas production. The possible amount of the understatement is completely unknown." (University of Melbourne [1])

Throughout the Australian CSG fields, there are likely to be thousands of high-point vents continuously venting methane. Community members have recorded and reported methane vents for several years. During our short visit to the CSG fields we recorded a number of continuously-emitting vents.

What is the purpose of a high-point vent? Prior to gas production, very large volumes of water must be pumped out of the coal seams in order for gas to then follow. Environmental regulations require that this coal-seam water be treated (e.g. for salt removal) prior to release back into the environment. This "produced" water is collected into a vast network of water-gathering pipelines that transport the water across distances of tens to hundreds of kilometres to central water processing facilities such as reverseosmosis plants.

Produced water contains methane. As produced water travels through the watergathering pipelines, methane gas separates from the water. Methane gas in the water pipelines can hinder water pipeline operations. Therefore high-point vents are used across this network to vent off this methane into the Earth's atmosphere. High-point vents are used wherever the terrain being crossed by these water pipelines features a high point in elevation.

If one ignores all other equipment and operations in the CSG fields, methane emissions from thousands of high-point vents spread throughout the CSG fields could, by themselves, exceed the ambitiously-low methane-emission commitments made by the CSG-LNG project proponents in their Environmental Impact Statements.

In addition to quantifying methane emissions from vents, gas companies should also measure and report non-trivial methane emissions from all other sources such as flares, other gas combustion devices, water treatment facilities, leaks from equipment, and intermittent releases (discussed next).

Intermittent methane releases

In addition to *continuous* sources of methane emissions such as high-point vents, there are thousands of locations across the Australian CSG fields where large volumes of methane can be *intermittently* released from equipment. Release duration can last from minutes to hours.

As indicated by the photograph of a warning sign below, gas producers will intermittently release methane from equipment for the purposes of pressure control and equipment purging. Methane can be discharged from equipment and piping at high velocity, which can result in high sound (noise) levels. If there are people living in the area, these intermittent releases can lead to residents filing noise complaints.



A sign warning of intermittent methane gas releases from Queensland CSG equipment.

The following video recording audibly and visually illustrates an intermittent methane release in the Queensland CSG fields. (Infrared imaging does not feature in this video.)



Video link: https://vimeo.com/206775927

The next video begins with a visual image (with audio) of an intermittent methane release in the Queensland CSG fields. The visual image is then followed by infrared video that allows the emitted methane to be seen.



Video showing intermittent methane releases in the Queensland CSG fields. Visual followed by infrared. (Link here: <u>https://vimeo.com/206776003)</u>

The following map shows more than 30 coal seam gas wells, vents, and other equipment situated near one home near Chinchilla, Queensland. Over 5,000 wells have so far been drilled in the CSG fields of Queensland and New South Wales with tens of thousands more wells planned.

Residents living near CSG infrastructure have witnessed and recorded many intermittent methane releases.



Map showing more than 30 CSG wells, vents, and other equipment around a residence near Chinchilla Queensland. Gas wells shown by red diamonds. Other gas-field equipment shown by yellow circles and red triangles.

Methane bubbling from the Condamine River

In addition to examining methane emissions from CSG equipment, we also used the FLIR GF-320 infrared-sensing video camera to record evidence of methane bubbling from the Condamine River.

Increasing volumes of methane bubbling from the Condamine River have been reported since the onset of CSG operations in the area. Data available from the gas-producing organisation APLNG indicates that the volume of gas discharging from the river quadrupled from September 2013 to January 2016 [2]. In April 2016, an observer ignited the bubbling methane. This resulted in flames appearing on the surface of the river.⁸



The Border Mail: "Condamine River on Fire in CSG Mining Area"9

Data published by the gas-producing organisation APLNG indicates that the volume of gas discharging from the river quadrupled from 500 litres per minute in September 2013 to nearly 2,000 litres per minute in January 2016 [2]. For comparison, a gas flow of 2,000 litres per minute, if constant over a year, is equivalent to the amount of gas required to supply around 800 traditional Melbourne gas-using homes. That volume of methane is also the greenhouse-gas equivalent of 65,000 tonnes per year of carbon dioxide.

APLNG has now placed large "upside-down buckets" on the bottom of the river in order to capture some of this bubbling gas. From the "buckets", APLNG has installed pipelines to take the gas away to a vent and two flares.¹⁰

⁸ <u>http://www.smh.com.au/comment/the-video-that-set-the-internet-alight--and-what-it-means-for-nsw-politics-20160429-goiimq.html</u>

⁹ http://www.bordermail.com.au/story/3866204/condamine-river-on-fire-in-csg-mining-area-photos-video/?cs=2609

¹⁰ <u>https://www.aplng.com.au/topics/coal-seam-gas/condamine-river-seeps.html</u>

INFRARED VIDEO-RECORDING METHANE EMISSIONS IN THE QUEENSLAND COAL SEAM GAS FIELDS - FEBRUARY 2017



Photograph of two flares burning gas collected from the bottom of the Condamine River.



Infrared image of methane gas (black fumes) being vented, after collection from the bottom of the Condamine River, Queensland. Video-recording available at this link: <u>https://vimeo.com/206778053</u>

INFRARED VIDEO-RECORDING METHANE EMISSIONS IN THE QUEENSLAND COAL SEAM GAS FIELDS - FEBRUARY 2017

Despite APLNG's efforts to divert methane emissions from the river, methane gas continues to bubble from the river as shown in the following photograph and in visual and infrared video recorded in February 2017. With infrared imaging in the video, methane emissions appear as black fumes and bubbles persisting on the surface of the river.



Photograph of bubbling Condamine River, February 2017. The bulk of the gas is being captured by "upside-down buckets" placed on the river bed. Captured gas then piped to onshore vents and flares. See visual and infrared video of methane bubbles at the following link: <u>https://vimeo.com/206778242</u>

According to APLNG [2] and a study by Norwest [13], the potential causes and contributing factors of the methane bubbling from the Condamine River include human activity such as CSG operations and drawing water from bores, as well as the underlying geology and natural events such as drought and flood cycles.

Wambo Creek bubbling

Though lesser in volume when compared with what is happening at the Condamine River, we also observed bubbles in Wambo Creek, where Avenue Road crosses the creek. This location is about ten kilometres from the Condamine River location.

The following map locates the Wambo Creek site (yellow circle) in relation to the Condamine River and CSG wells (blue dots).



Map of Condamine River and Wambo Creek CSG-producing areas. Locations of CSG wells shown by blue dots. Wambo Creek bubbles shown by yellow circle.

The following photograph and video records bubbles from Wambo Creek.



Bubbles emanating from Wambo Creek, Queensland Video available here: <u>https://vimeo.com/206779840</u>.

Methane bubbling from the Condamine River and Wambo Creek could be examples of migratory methane emissions. Migratory emissions are defined as where, as a result of unconventional oil and gas development, methane may migrate upward and laterally out of its original reservoir. Migratory methane may eventually reach the Earth's surface and enter the atmosphere at a considerable distance away from the site of original oil and gas drilling or other disturbance [1].

According to APLNG [2] and a study by Norwest [13], the potential causes and contributing factors of the methane bubbling from the Condamine River include human activity such as CSG operations and drawing water from bores, as well as the underlying geology and natural events such as drought and flood cycles.

7. U.S.: AIRBORNE INFRARED QUANTIFIES METHANE EMISSIONS

The FLIR GF-320 camera is not able to measure the amount of methane gas being released from a vent or other release point (e.g. in kilograms per hour). However, using other infrared-sensing equipment, "top-down" methane-emission measurements have been reported in the United States.

Most significantly and recently, Frankenberg et al. used airborne infrared imaging in the "Four Corners" region of the United States to identify 250 individual methane plumes and to quantify methane emission rates ranging from two kilograms to five tonnes per hour [3]. One reason the Four Corners region is of interest is because satellite observations across the entire U.S. indicated a unique "hot-spot" of very large methane emissions from this area [4]. The Four Corners region is the largest source of coal seam gas in the United States.¹¹



Methane-emissions 'hot-spot' over the Four Corners region of the U.S. revealed by satellite measurements [4].

¹¹ Oil and gas is also produced by conventional means in this region.

This research of Frankenberg et al., funded by National Aeronautics and Space Administration (NASA) and the National Oceanographic and Atmospheric Administration (NOAA), used a "next-generation Airborne Visible/Infrared Imaging Spectrometer (nearinfrared)" and a "Hyperspectral Thermal Emission Spectrometer (thermal infrared)" mounted in a fixed-wing aircraft.

The researchers measured methane plumes at one to three metre spatial resolution across an area 80 kilometres x 40 kilometres. The figure below shows the study area and identified emission sources.



Map of airborne methane investigations in the Four Corners region of the United States, from Frankenberg et al. [3]. Emission sources shown as coloured dots.

------ 30 INFRARED VIDEO-RECORDING METHANE EMISSIONS IN THE QUEENSLAND COAL SEAM GAS FIELDS - FEBRUARY 2017 The table and images below show quantitative results for four of the 250 methaneemissions sources identified.

Image number	Emission source	Emission rate (kilograms / hour)	Emission rate (tonnes / day)
5	well pad	500	12
6	coal mine venting shaft	1,100	26
7	sources undetermined, located near well-completion site	1,200	29
8	gas processing plant	5,000	120



Imaging and quantifying methane emissions in the "Four Corners" region of the southwestern United States [3].

At the following link is a video from Frankenberg et al. [3] showing methane emissions from an underground gas pipeline. A visual image is followed by an infrared video (black and white palette) where methane fumes appear as black.



Click on link to access video: <u>http://movie-</u> usa.glencoesoftware.com/video/10.1073/pnas.1605617113/video-2

The following image is an aerial representation of the above pipeline leak. The methane emission rate was found to be 50 kilograms per hour.



Aerial imaging of a pipeline leak in the Four Corners region of the United States (Methane leaking at a rate of 50 kilograms-per-hour) [3].

We recommend the "top-down" techniques used by Frankenberg et al. be applied to current and prospective Australian unconventional oil and gas-producing regions.

8. RECOMMENDATIONS AND FURTHER WORK

The Australian Government should not ignore the evidence of large methane emissions from CSG operations that has been highlighted by the CSIRO in 2014 and is reinforced by this report.

The potential for large volumes of methane being released from thousands of release points across the CSG fields calls into question the ambitious methane-emission targets set by the CSG-LNG industry in their Environment Impact Statements, and also the very low assumption and factor-based estimates of methane emissions used and reported by the Australian Government.

The University of Melbourne recommended further investigation into methane emissions in the CSG fields. These are listed below [1]:

"Given the scale of Australia's prospective unconventional oil and gas reserves, ..., and the uncertainty surrounding current and future emissions, it is critical that greater certainty and transparency is established around the industry's methane emissions. To ensure that methane emissions from unconventional oil and gas production are minimised we recommend that:

- in existing and prospective unconventional oil and gas production regions, baselines are established so that the methane-emissions character of a region is known prior to expansion of oil and gas production or deployment of wells and other equipment
- commitments made by CSG-LNG producing companies in Environmental Impact Statements (EISs) are mandated and confirmed with regular, rigorous, and verifiable audits. Factor-based assumptions should be replaced with direct measurement where emissions may be significant.
- the latest-globally-available technologies and techniques are used to detect, quantify, cross-check, and minimise methane emissions
- priority is given to the implementation of methane-emission-detection techniques that can ensure no 'super-emitters' go undetected."

With respect to understanding migratory methane emissions, researchers at the University of Melbourne also recommended the development of:

"...an integrated geological-hydrological model. This model would assess the implications of formation heterogeneity, irregular formation thickness, coal seam dewatering and depressurisation, and water extraction by all users." [6]

Furthermore, given the remarkable results reported recently for the "Four Corners" region of the U.S., the techniques used by Frankenberg et al. [3] should be applied in Australian coal seam gas regions, both to establish baselines in prospective areas and also to quantify emissions from existing operations. Quantifying methane emissions from the thousands of existing high-point vents should be an area of immediate focus.

Lastly, the Narrabri CSG project currently under-review [5] should not be approved on the basis of continued use of these inappropriate methane-emission estimates. Rather, real-world data now available from years of Queensland CSG operations should be published, reviewed by independent assessors, and used as the basis for project commitments.

9. **BIBLIOGRAPHY**

- D. Lafleur, T. Forcey, H. Sadder, and M. Sandiford, "A review of current and future methane emissions from Australian unconventional oill and gas production," Melbourne Energy Institute, University of Melbourne, 2016.
- [2] APLNG. Condamine River Seeps. [Online]. <u>https://www.aplng.com.au/topics/coal-seam-gas/condamine-river-seeps.html</u>
- [3] C. Frankenberg et.al., "Airborne methane remote measurements reveal heavy-tail flux distribution in Four Corners region," *Proceedings of the National Academy of Sciences*, vol. 113, no. 35, August 2016.
- [4] E. Kort et al., "Four corners: The largest US methane anomaly viewed from space," *Geophysical Research Letters*, 2014.
- [5] Santos, "Narrabri Gas Project Environmental Impact Statement Chapter 24," 2017.
- [6] D. Lafleur and M. Sandiford, "The risk of migratory methane emissions resulting from the development of Queensland coal seam gas," Melbourne Energy Institute, University of Melbourne, (in publication).
- [7] T. Forcey, "Switching off gas. An examination of declining gas demand in Eastern Australia," University of Melboure Energy Institute, 2015.
- [8] S. Day, M. Dell'Amico, R. A. Fry, and H. Javanmard Tousi, "Field Measurements of Fugitive Emissions form Equipment and Well Casings in Australian Coal Seam Gas Production Facilities," CSIRO, 2014.
- [9] The Australia Institute. [Online]. <u>http://www.tai.org.au/content/review-current-and-future-methane-emissions-australian-unconventional-oil-and-gas-production</u>
- [10] UNFCCC, "Report on the individual review of the inventory submission of Australia submitted in 2015, Note by the expert review team," 2016.
- [11] Australian Government, "National Inventory Report 2014 and Revised Kyoto Protocol National Inventory Report 2013," 2016.
- [12] M. Galfalk, G. Olofsson, P. Crill, and D. Bastviken, "Making methane visible," *Nature Climate Change*, 2015.
- [13] Norwest Energy Consultants Pty Ltd, "Condamine River seep investigation technical report," 2014.