FUTURE FUELS CRC

A Methodology Document Detailing Biomethane Testing and Injection Pathways to Meet Existing Australian Standards and Regulatory Requirements

July 24, 2022

RP3.2-09

Biomethane Impurities

Authors:

Ehsan Soroodan Miandoab, Research Fellow, School of Chemical and Biomedical Engineering, University of Melbourne
Sandra Kentish, Head of School, School of Chemical and Biomedical Engineering, University of Melbourne

Project team:

Research Team

Sandra Kentish, Head of School, School of Chemical and Biomedical Engineering, University of Melbourne
Colin Scholes, Associate Professor, School of Chemical and Biomedical Engineering, University of Melbourne
Amanda Ellis, Head of Chemical Engineering, School of Chemical and Biomedical Engineering, University of Melbourne
Ehsan Soroodan Miandoab, Research Fellow, School of Chemical and Biomedical Engineering, University of Melbourne
Holger Maier, Professor, School of Civil, Environmental and Mining Engineering, University of Adelaide
Sam Culley, Postdoctoral Research Fellow, School of Civil, Environmental and Mining Engineering, University of Adelaide

Industry Advisory Team

Siew Shan Foo, Facilities Engineer, Jemena
Shreyas Rajpurkar, Capacity Planning Engineer, Jemena
Huw Evans, Operational Support Engineer, Jemena
Christopher Larkin, Commercial Manager Renewable Gas, Jemena
James McHugh, Project Engineer, APA Group
Xiaoda Xu, Corrosion Specialist, Origin Energy
Justin Brown, Senior Pipeline Engineer, Santos

Australian Government
Department of Industry, Science, Energy and Resources

Business Cooperative Research Centres Program

This work is funded by the Future Fuels CRC, supported through the Australian Government's Cooperative Research Centres Program. We gratefully acknowledge the cash and in-kind support from all our research, government and industry participants.

IMPORTANT DISCLAIMER

ACKNOWLEDGEMENT

This work is funded by the Future Fuels CRC, supported through the Australian Governments' Cooperative Research Centres Program. The cash and in-kind support from the industry participants is gratefully acknowledged.

PROJECT INFORMATION	
Project number	RP3.2-09
Project title	Biomethane Impurities
Research Program	Research Program 1. Future Fuel Technologies, Systems and Markets
Milestone Number	4
Description	A methodology document detailing biomethane testing and injection pathways to meet existing Australian Standards and regulatory requirements
Research Provider	The University of Melbourne
Project Leader and Team	Sandra Kentish, Colin Scholes, Amanda Ellis, Ehsan Soroodan Miandoab, Holger Maier, Sam Culley
Industry Proponent and Advisor Team	Siew Shan Foo, Shreyas Rajpurkar, Huw Evans, Christopher Larkin, James McHugh, Xiaoda Xu, Justin Brown
Related Commonwealth Schedule	RP3.2.1 Improved thermodynamic models and design software for pipelines transporting fuels delivered. RP3.2.4 Recommendations for improved industry standards based on research into design / operation of fuel infrastructure
Project start/completion date	Nov 2020 / Dec 2022
IP Status	Public Domain
Approved by	Siew Shan Foo, Jemena
Date of approval	July 2022

Abbreviations

Abbreviation	Definition
AED	Atomic Emission Detector
AS4564	Australian Standard Specification for general-purpose natural gas
GC	Gas Chromatography
NERL	National Energy Retail Law
STTM	Short Term Trading Market
TCD	Thermal Conductivity Detector

Contents

SUMMARY OF REPORT

This report aims to provide regulatory and technical information regarding biomethane injection into existing natural gas pipelines by undertaking two primary tasks:

- Reviewing state-by-state Acts, Laws and Regulations concerning quality requirements for natural gas transmission and distribution in Australia; and generating guidance on steps to be taken to facilitate biomethane injection in compliance with these regulations and with Australian Standard AS 4564.

- Performing computer-aided simulations to study natural gas and biomethane mixing under industrial conditions, track biomethane contaminants in natural gas pipelines and determine the mixing conditions that result in compliance with AS 4564 at the end user.

The review of state-by-state legislation identified clauses that relate to natural gas quality requirements. Wherever the legislation could be interpreted as allowing the extension of quality requirements to cases other than natural gas, guidance outputs detailing their applicability to biomethane injection have been produced. The guidance outputs identify the need for a new or amended safety and operating plan for biomethane-blended gas transport in existing natural gas pipelines. The amended plan is likely to include both feedstock and biomethane gas quality monitoring; as well as gas mixing studies that can predict the concentration of biomethane contaminants downstream of the injection point to ensure gas of AS4564 quality is delivered to end-use customers. The gas quality monitoring should be based on procedures and techniques already developed for biomethane promotion in other countries particularly for unconventional contaminants such as siloxanes. Computational Fluid Dynamics (CFD) simulations of biomethane and natural gas mixing show that a close to fully mixed flow can be achieved within a short distance from the injection point, resulting in uniform concentrations of contaminants at the point of end-use. Consequently, these concentrations can be estimated using mass balance calculations without requiring CFD simulations. Results showed compliant mixing was feasible for a range of biomethane compositions if natural gas concentrations were well within the compliance limits.

1 BACKGROUND

The promotion and use of renewable energy supplies like biomethane will play a pivotal role in decarbonizing and consolidating Australia's energy sector. Produced from biogas upgrading processes involving Carbon Dioxide (CO_2) and Hydrogen Sulphide (H_2S) removal, biomethane's major constituent is Methane (CH_4), similar to natural gas, giving it the potential for being blended into existing natural gas grids and eliminating the need for the construction of independent biomethane transmission and distribution infrastructure. However, depending upon the source from which the biomethane is produced, it may contain contaminants that are not present in natural gas. A previous literature review on biomethane impurities revealed that the contaminants of concern are either similar to those found in natural gas (such as Oxygen (O_2)) but at elevated concentrations; or can be classified as "unconventional" and specific to the feedstock from which the biomethane is derived [1]. These unconventional contaminants can include siloxanes, ammonia, halocarbons and volatile organic compounds. The literature review analysed regulatory requirements in over 18 different biomethane-producing jurisdictions and proposed limit values for the concentrations of unconventional contaminants in natural gas pipelines that can be adopted by Australian decision-makers to facilitate biomethane injection. Equally importantly, the literature review concluded that no changes are required for most of the quality parameters mandated by AS 4564 (e.g. higher heating value (HHV), hydrocarbon dew point and hydrogen sulphide content). However, there would be concerns about maximum allowable O_2 and inert gas (primarily Nitrogen (N_2) and CO_2) concentrations due to their elevated levels in biomethane, relative to natural gas. The current AS 4564 limit for O_2 is 0.2 mol% but studies show its concentration within biomethane can reach up to 2 mol% [2]. Bringing O_2 levels down to the AS 4564 limit is not always viable from the biomethane producers' perspective due to significant additional costs [3]. Similarly, studies show that the inert gas content in the biomethane derived from landfill gases can be up to 10 mol% against 7 mol% as the maximum allowable limit in AS 4564 [3]. Since the Wobbe Index (WI) is intrinsically tied to the concentration of inert gases, there is also concern about the lower WI limit. As a result, work is required to create quality standards and/or safety and operating plans based on Australian legislation to ensure that no adverse impacts from biomethane impurities are imposed on both pipeline owners/operators and end-point customers.

This report is focused on the creation of a methodology document for biomethane injection into the Australian natural gas network based on:

- Gas quality compliance requirements from state-by-state legislation associated with natural gas transport in pipelines.
- Guidance outputs derived from the state-by-state legislation outlining safety and operational requirements for natural gas flow in pipelines that can be extended to biomethane injection.
- Computational Fluid Dynamics (CFD) studies investigating the effectiveness of natural gas and biomethane mixing to determine conditions that result in AS 4564 compliant gas at the end-user, as a function of the concentration of O_2 and inert gases in the feed biomethane, as well as biomethane and natural gas flowrates.

Excluded from this report are:

- The possibility of changes to AS 4564 limits for O_2 and inert gases, as well as lower WI index. Project RP1.4-07 is currently studying the influence of increased O_2 and inert gas concentrations on end-user appliances. Similarly, Milestone 5 of this project will complete a desktop review and corrosion modelling for integrity-based impacts of raising AS-4564 oxygen limits on Australian natural gas networks. Only after these two projects have been completed will there be sufficient evidence to consider the possibility of changes to AS 4564.
- Mixing studies on the influence of unconventional contaminants (e.g. siloxanes and ammonia, etc.) on the final composition of the blended gas delivered to customers.

2 TARGETED REGULATIONS

Project RP1.2-04 has recently identified viable locations for biomethane production and injection in natural gas pipelines [4]. The locations are primarily based in the states of Victoria (VIC), New South Wales (NSW), Queensland (QLD) and Southern Australia. Hence, natural gas regulations of these states were studied in the present project. Presented in Table 1 are the targeted regulations alongside their objectives in the framework of natural gas quality requirements.

Table 1. Objectives of state-by-state Laws, Acts and Regulations in the framework of safety and quality requirements for natural gas transmission and distribution

Sate	Acts/Laws/Regulations	Objective
NSW	**National Gas Law No. 31a**	Promoting efficient investment in, and efficient operation and use of, natural gas services for the long-term interests of consumers of natural gas with respect to price, quality, safety, reliability, and security of supply of natural gas.
	Gas Supply Act 1996 No. 38	- Promoting the thermally efficient use of gas and delivering a safe and reliable supply of gas - Regulating gas reticulation and gas supply, so as to protect the interests of customers, - Facilitating the continuity of supply of natural gas to customers - Promoting the safe use of gas.
	Gas Supply (Safety and Network Management) Regulation 2013	Detailing technical and regulatory requirements for natural gas distribution network operators
	Pipeline Regulation 2013	Detailing regulatory requirements for natural gas pipeline design, operation, maintenance, management, alteration, and inspection
VIC	**Gas Industry Act 2001**	Regulating the gas industry with provisions in relation to the gas and pipeline definitions, tariffs and charges, licenses, sale and supply of the gas, gas market, etc.
	National Gas (Victoria) Act 2008	Providing for the establishment of a national framework to enable third parties to gain access to certain natural gas pipeline services
	National Gas (Victoria) (Declared System Provisions) Regulations 2014	The objective of these Regulations is to prescribe, for the purposes of the National Gas (Victoria) Law, certain provisions of the National Gas Rules to be— (a) civil penalty provisions; or (b) conduct provisions.
	Gas Safety Act 1997	Making provision for the safe conveyance, sale, supply, measurement, control, and use of gas and generally regulating gas safety.
	Gas Safety (Safety Case) Regulations 2018	Prescribing safety standards for the quality of gas and the testing of natural gas conveyed through a transmission pipeline.
QLD	**Petroleum and Gas (Production and Safety) Act 2004**	- Regulating the carrying out of petroleum activities and the use of petroleum and fuel gas - Regulating the construction and operation of pipelines *Note:* Petroleum activities mean the exploration, distillation, production, processing, refining, storage, and transport of petroleum and fuel gas.

	Petroleum and Gas (Safety) Regulation 2018	Prescribing safety requirements for natural gas quality and natural gas network operation
SA	**National Gas (South Australia) Act**	Promoting efficient investment in, and efficient operation and use of, natural gas services for the long-term interests of consumers of natural gas with respect to price, quality, safety, reliability, and security of supply of natural gas.
	Gas Act 1997	Establishing and enforcing proper standards of safety, reliability, and quality in the gas supply industry
	Gas Regulations 2012	Providing safety and technical requirements for gas infrastructure, gas supply, and quality

3 GUIDANCE OUTPUTS

Relevant text from the above Acts, Laws and Regulations is provided in Appendix A. Guidance outputs generated from this text is provided in Table 2. In summary, the potential pathways to compliant biomethane injection is to seek exemptions from the current legislation and to create new or amended safety and operating plans containing measures in place to ensure the safety of the gas for both pipeline operators and end-users.

Table 2. Guidance outputs for biomethane injection derived from legislation

Sate	Guidance Output
NSW	▪ Negotiate modified Short Term Trading Market (STTM) procedures and/or Rules as needed to ensure compliance. ▪ Seek a distributor license to permit biomethane transmission in the pipeline. ▪ Prepare a new or amended Safety and Operating Plan that contains: ➢ An explanation of the extent of the departure from gas quality standards. ➢ The arrangements in place to ensure that an equivalent or safer outcome has been achieved despite that departure. ➢ Procedures and measures in place based upon engineering requirements and/or research studies to ensure the supply of reasonably safe gas to end-users. ➢ Additional gas testing to ensure compliance at the customer.
VIC	▪ Seek exemption from the requirement to obtain a licence under the authority of the Essential Services Commission of Victoria (Clauses 22 and 29c of Gas Industry Act 2001). ▪ Alternatively, use the procedures specified by the Essential Services Commission to modify industry codes and standards (Clause 31 of Gas Industry Act 2001). ▪ Seek exemption from the requirements of the Regulations, which may be given to a gas company by Energy Safe Victoria. • Modify the safety management system that is part of the safety case submitted to Energy Safe Victoria to account for the departure from gas quality requirements ▪ The wording "as far as practicable" and "complies with any other prescribed requirements" may open the door for adopting an alternative, more comprehensive quality requirement which would be applicable to biomethane (Clause 33 of Gas Industry Act 2001).
QLD	• Work with the Chief Inspector to develop a "gas quality agreement" as an exemption pathway.
SA	▪ Negotiate modified STTM procedures and/or Rules as needed to ensure compliance. ▪ Seek a National Energy Retail Law (NERL) retailer license to permit biomethane transmission in the pipeline. ▪ Alternatively, seek exemption from the Technical Regulator. ▪ Exemption pathway outlined under Clause 52

4 LIKELY COMPONENTS OF AMENDED SAFETY AND OPERATING PLANS

An amended safety and operation plan is likely to include:

Risk Assessment: A risk assessment will consider:

- The flowrate of biomethane to be injected into the transmission or distribution network, relative to the natural gas flowrate. A smaller proportion of biomethane relative to the total flow is lower risk and will require less additional monitoring.
- The duration of the biomethane injection. A short-term trial is likely to have less effect on pipeline and end-user appliance integrity than a permanent installation.
- The pipeline length between the injection point and the end user. A longer length ensures complete mixing of the gas supplies (see Section 5).

- The source of the biomethane supply. For example, biogas derived from agricultural waste such as dairy waste is highly unlikely to contain siloxanes or halogenated compounds, so monitoring of these potential contaminant should not be required [1]. Similarly, only landfill derived gas contains significant concentrations of ammonia, hydrogen sulphide and carbon monoxide. Refer to Milestone Report 2 (Literature Review) Tables 4 and 46 [1].
- Quantitative composition data for both the biogas and biomethane, based on initial pilot plant or laboratory trials. Alternatively, pre-injection testing over a period of some weeks may be needed before acceptance by the grid operator[5].
- The processes used to upgrade the biogas into biomethane, as some are more effective than others in reducing specific contaminant concentrations. Refer to Milestone Report 2 (Literature Review) Table 8 [1].
- Quantitative composition data for the underlying natural gas, particularly any residual water vapor concentrations. A combination of elevated water concentrations in the natural gas, with high oxygen concentrations in the biomethane could lead to elevated pipeline corrosion rates. This will be the subject of our Milestone 5 report.

Biomethane Feedstock Monitoring: It will often be easier to monitor contaminants as they occur in the raw biogas or the raw biomass feedstock, rather than the upgraded biomethane, due to the higher concentrations. Typical biogas concentrations for a range of contaminants and the corresponding biomethane concentrations are provided in Milestone Report 2 (Literature Review) Tables 28 - 41 [1]

Biomethane Quality Monitoring: Standard attributes that already have existing limit values in AS 4564 (such as total inert concentration and heating value) should be continuously monitored at the point of biomethane injection using the procedures developed for standard natural gas. This is commonly Gas Chromatography (GC) analysis with a Thermal Conductivity Detector (TCD) following ASTM D1945/1946 [6]. Other potential contaminants without existing limit values in AS 4564 (e.g. siloxanes) can be monitored by taking quarterly or annual samples of the gas for testing by an independent certified third-party laboratory [5], particularly if feedstock monitoring is also in place. Refer to Milestone Report 2 (Literature Review) Table 12 [1] for potential testing methods.

Gas Quality Monitoring Downstream of Injection Point: Standard attributes that already have existing limit values in AS 4564 should be continuously monitored using established procedures at a suitable point at least 50m downstream of injection to confirm mixing of natural gas and biomethane is complete.

Outcomes of research studies on biomethane and natural gas mixing: The mixing of biomethane and natural gas may result in a gas non-compliant with AS 4564 due to the elevated concentrations of O_2 and N_2. Computational Fluid Dynamics (CFD) simulations can provide three-dimensional concentration distributions of individual contaminants downstream of injection. This can determine what biomethane compositions can be injected into natural gas pipelines to be AS 4564 compliant gas upon reaching end-users. See Section 5 below for typical simulations.

5 CFD SIMULATIONS OF NATURAL GAS AND BIOMETHANE MIXING

5.1 Simulation Details

The basis for our CFD simulations are provided in Table 3. The temperature and pressure of the simulations are typical of underground natural gas transmission pipelines. Natural gas is assumed to be limited to the components shown in Table 3, even though it can contain other minor components not listed here. The concentrations of O_2

and inert gases (N_2 plus CO_2) were set to their maximum limit values in AS 4564, 0.2 mol% and 7 mol%, respectively, as no reference composition for natural gas in Australian pipelines was found. This natural gas composition represents an extreme case where the concentrations of O_2 and inert gases are likely much greater than their typical values. Similarly, biomethane composition was intentionally varied in a way to allow for the introduction of very high levels of contaminants to the natural gas pipelines. As a result, the mixing studies consider "worst-case" scenarios where the concentrations of the contaminants in natural gas pipelines are probably more than the concentrations under industrial conditions.

Table 3. CFD simulation basis for biomethane and natural gas mixing studies

Simulation Parameter/Variable	Value
Temperature	14 °C
Pressure	50 bar
Natural gas composition	90 mol% CH_4, 2 mol% C_2H_6, 0.8 mol% C_3H_8, 5 mol% N_2, 2 mol% CO_2, 0.2 mol% O_2
Natural gas flowrate	500-10000 STD m^3/h
Biomethane composition	3-8 mol% N_2, 2 mol% CO_2, 1-3 mol% O_2, CH_4 balanced
Biomethane flowrate	0.06 to 0.5 as a ratio to the incoming natural gas flowrate (NOT the combined natural gas and biomethane flowrates)
Natural gas pipeline characteristic	250 DN
Biomethane pipeline characteristic	150 DN
Blending pipeline length	20 m, 40 m

5.2 Simulation Results

Typical O_2 compositions after biomethane and natural gas blending is shown in Figure 1. Two pipeline lengths of 20 m and 40 m were used for the simulations with the biomethane composition set to 8 mol% N_2, 2 mol% O_2 and 2 mol% CO_2 . The natural gas flowrate is 8600 STD m^3/h (165 actual m^3/h) while the biomethane flowrate is 1600 STD m^3/h (30 actual m^3/h) giving a ratio of biomethane to natural gas flow of 0.18. Results show a close to fully mixed flow within relatively short distances from the injection point, representing insignificant changes in contaminant concentrations within the natural gas pipeline.

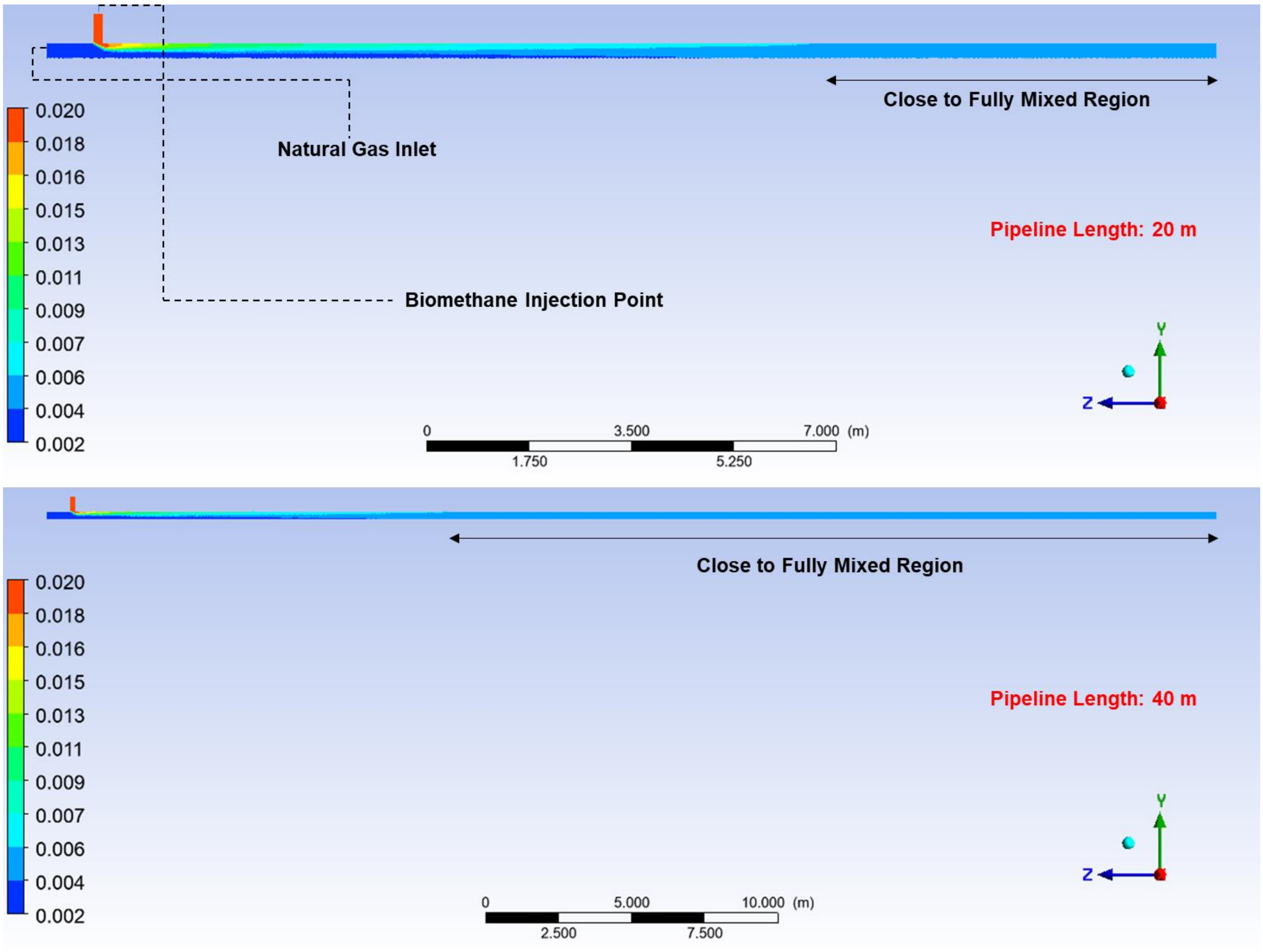

Figure 1. The mole fraction of O_2 in natural gas pipeline after blending with biomethane. Top and bottom contours represent simulation results for pipelines of 20 m and 40 m, respectively. The biomethane contained 2 mol% oxygen and the ratio of biomethane to natural gas flow was 0.18.

To better visualize the extent of mixing, Figure 2 shows a comparison of the oxygen mol fraction at the upper edge of the pipe versus the average value at different locations within the pipeline. The two mole fractions converge with less than 5% difference both in radial and axial directions after 20 m, as the flow becomes close to fully mixed downstream of the injection point. Achieving a fully mixed flow within a short distance from the injection point is the major outcome of these CFD studies, as it ensures the gas delivered to end-use customers will have consistent specifications.

Another simulation considered the blending of the same proportion of raw biogas into natural gas (i.e. a ratio of 0.18 and a total flowrate of 10,200 STD m^3h). A biogas composition of 50 mol% N_2, 10 mol% O_2 and balance CH_4 was chosen in order to simulate worst-case conditions. Again, a close to fully-mixed flow is achieved within a short distance from the injection point (Figure 3). The average and upper edge concentrations are again close to identical within 20 m of the mixing point, even though the biogas is significantly different in composition (Figure 4).

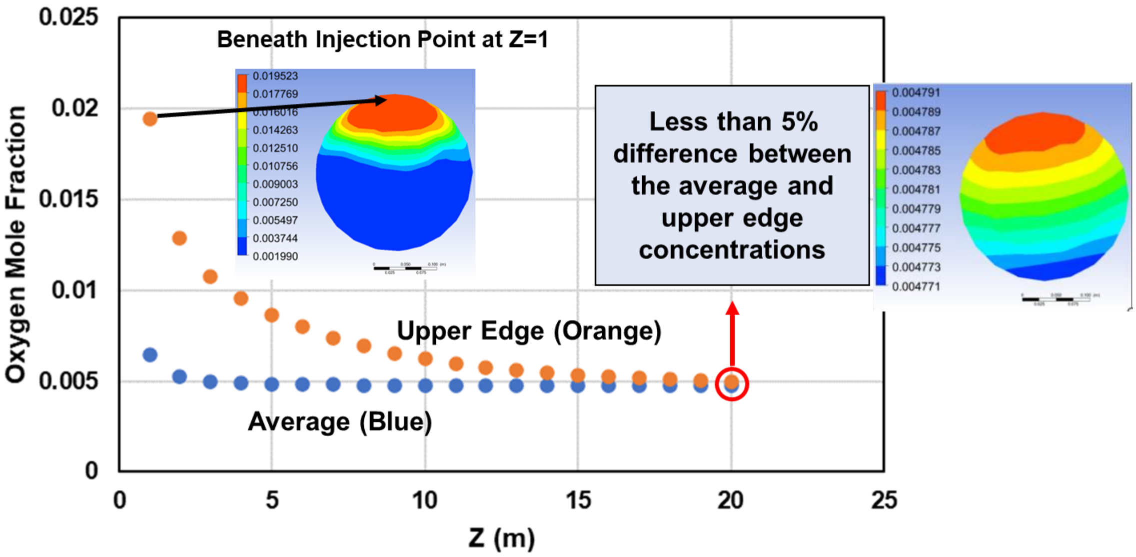

Figure 2. Upper edge versus average mole fractions of O_2 as a function of pipeline length. Note the difference in scale used in the inset spheres. The biomethane contained 2 mol% oxygen. The natural gas flowrate is 8600 STD m3/h while the biomethane flowrate is 1600 STD m3/h, giving a ratio of biomethane to natural gas flow of 0.18.

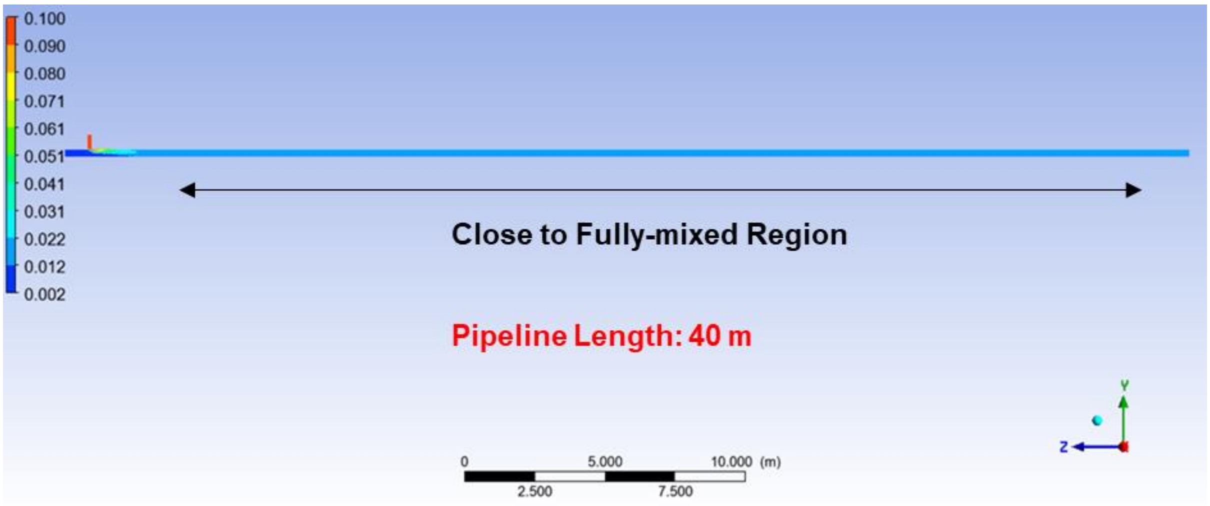

Figure 3. The mole fraction of O_2 in a 40 m natural gas pipeline after blending with a raw biogas composed of 50 mol% N_2, 10 mol% O_2 and CH_4 balanced. The natural gas flowrate is 8600 STD m3/h while the biogas flowrate is 1600 STD m3/h, giving a ratio of biogas to natural gas flow of 0.18.

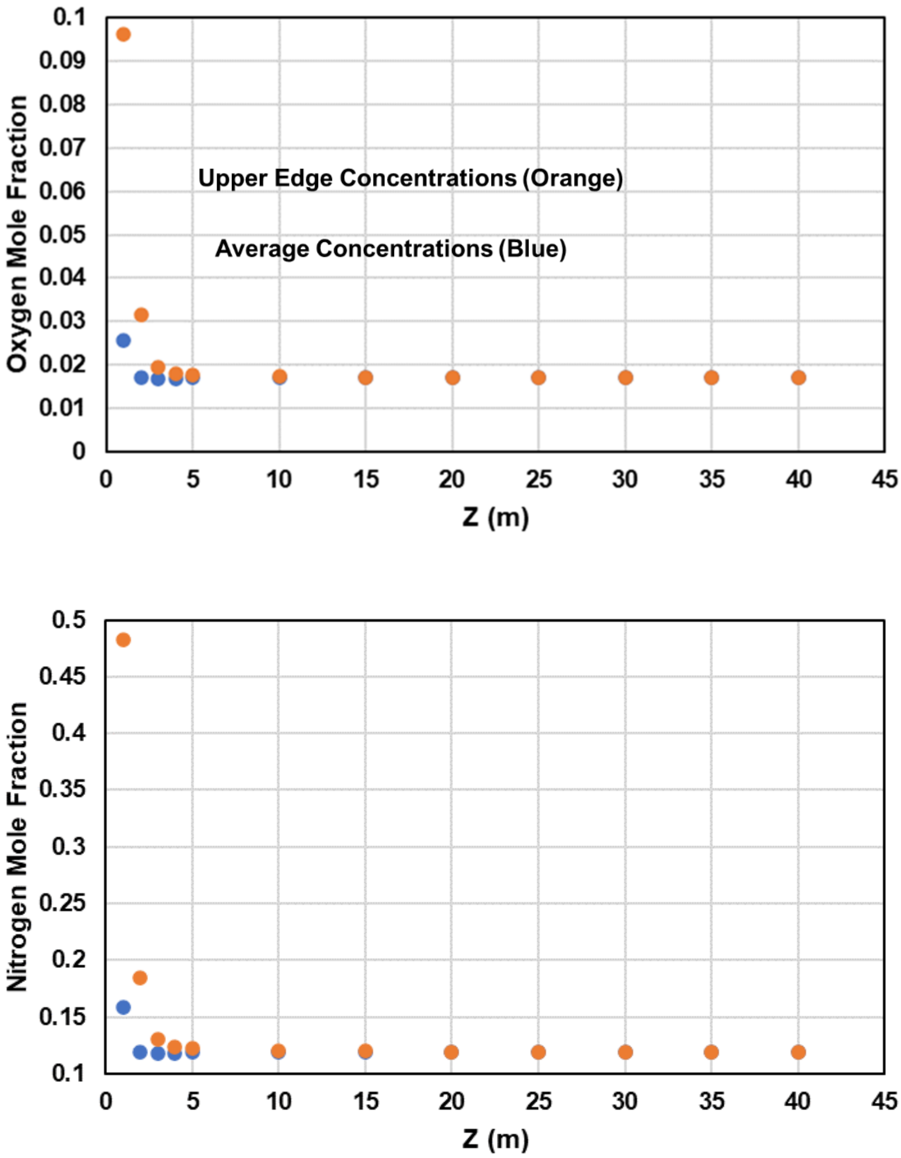

Figure 4. Upper edge versus average mole fractions of O_2 and N_2 as a function of pipeline length when blending raw biogas and natural gas. The raw biogas contains 50 mol% N_2, 10 mol% O_2 and CH_4 balanced. The natural gas flowrate is 8600 STD m3/h while the biogas flowrate is 1600 STD m3/h, giving a ratio of biogas to natural gas flow of 0.18.

Biomethane composition and flowrate, as well as natural gas flowrate were varied to investigate whether the fully mixed flow conclusion remains valid under various operating conditions. The average and upper edge concentrations continue to converge at a pipeline length of 20m as shown in Figures 5-7.

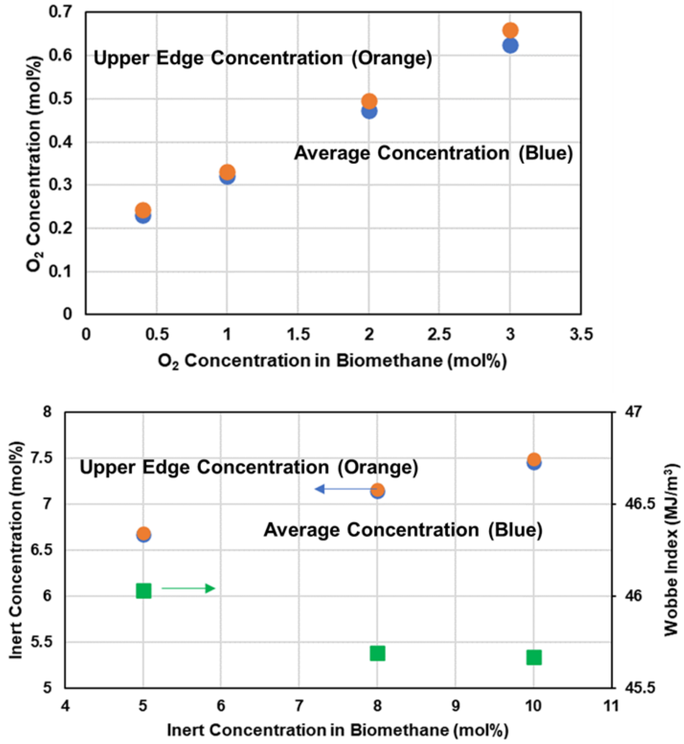

Figure 5. Effect of O_2 and inert gas concentrations in biomethane on the final mixed gas concentrations in a pipeline of length 20 m. Biomethane to natural gas flowrate was fixed at a ratio of 0.18. Other simulation details are listed in Table 3.

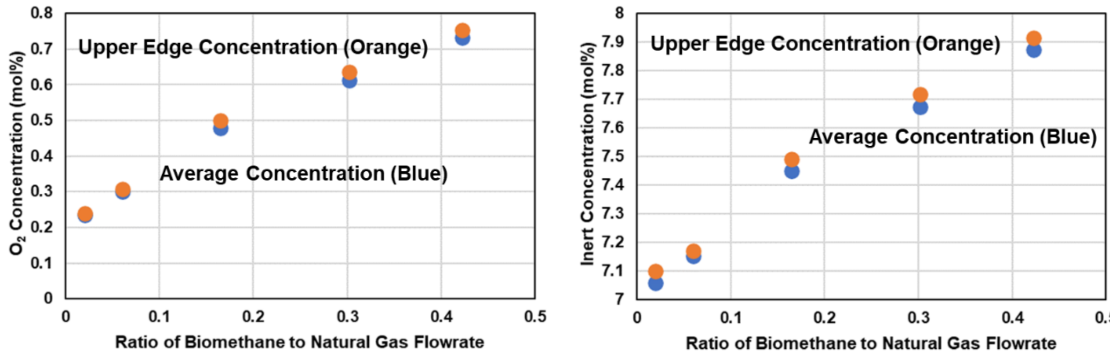

Figure 6. Effect of biomethane flowrate on the final mixed gas concentrations in the pipeline of length 20 m. Biomethane composition is set to 8 mol% N_2, 2 mol% O_2, 2 mol% CO_2 and CH_4 balanced. Other simulation details are listed in Table 3.

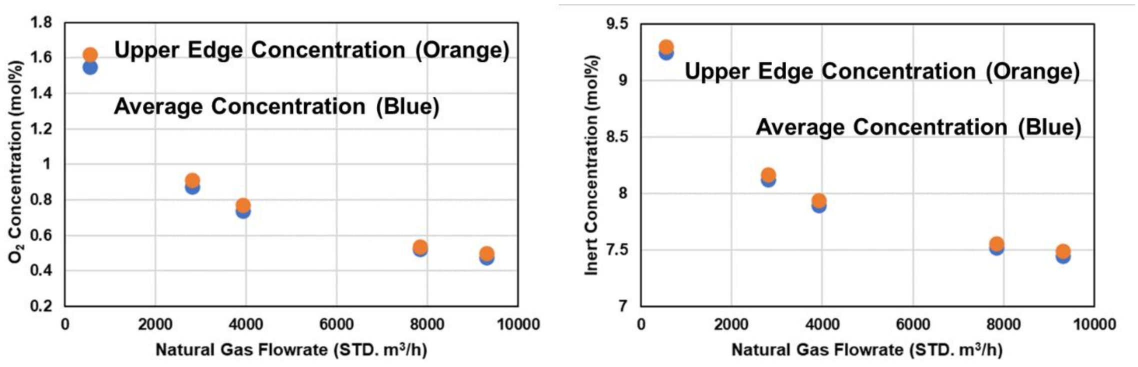

Figure 7. Effect of natural gas flowrate on the final mixed gas concentrations in the pipeline of length 20 m. Biomethane composition is set to 8 mol% N_2, 2 mol% O_2, 2 mol% CO_2 and CH_4 balanced. Other simulation details are listed in Table 3.

In all simulations, the final mixed gas concentrations exceeded the limit values mandated by AS 4564 because the maximum allowable concentrations of O_2 and inert gases were assumed as a starting point. Typical pipeline concentrations are likely much lower than the maximum limit values which would result in the mixed gas being compliant with AS 4564.

The results indicate that in all cases, performing CFD simulations is not necessarily required with the average mixture concentration calculated from a mass balance sufficient to calculate the composition of the blended gas, if more than 40m from the point of injection. If the calculated mixed gas concentration is within the limit values of AS 4564, then it can be injected into the natural gas pipeline.

6 CASE STUDIES OF GAS MIXING COMPLIANT WITH AS 4564

The aim of this section is to show under which conditions the mixing of biomethane with natural gas would be compliant with AS 4564. Based on the outcome of CFD simulations, simple mass balances are sufficient for this purpose, if injection is more than 40 m upstream of the end user. For these calculations, it was assumed that the natural gas was a binary mixture of 0.05-0.2 mol% O_2 with balance CH_4 which was mixed with a biomethane stream consisted of 1-3 mol% O_2 and balance CH_4. The mole fraction of O_2 is plotted as a function of the biomethane to natural gas flowrate in Figure 8, with the area of compliance with AS 4564 (i.e. maximum 0.2 mol% O_2) highlighted. At 0.05 mol% O_2 in natural gas and 1 mol% O_2 in biomethane, blending would be compliant if the ratio of biomethane to natural gas flowrate was set to 0.2 or less. When increasing the biomethane concentration of O_2 to 2 mol%, the biomethane flowrate should be $\leq$ 10% of the natural gas flowrate to have a compliant mixed gas. The area of compliant mixed gas becomes smaller when the natural gas contains 0.1 mol% O_2, with a ratio of 0.12 biomethane to natural gas flowrate needed for biomethane containing 1 mol% O_2. Figure 8 also shows compliant blending with O_2 levels greater than 1 mol% in biomethane. For instance, if the natural gas and biomethane concentrations of O_2 were set to 0.1 mol% and 2 mol%, the compliant blending would occur at biomethane to natural gas flowrate ratios of 0.06 or less.

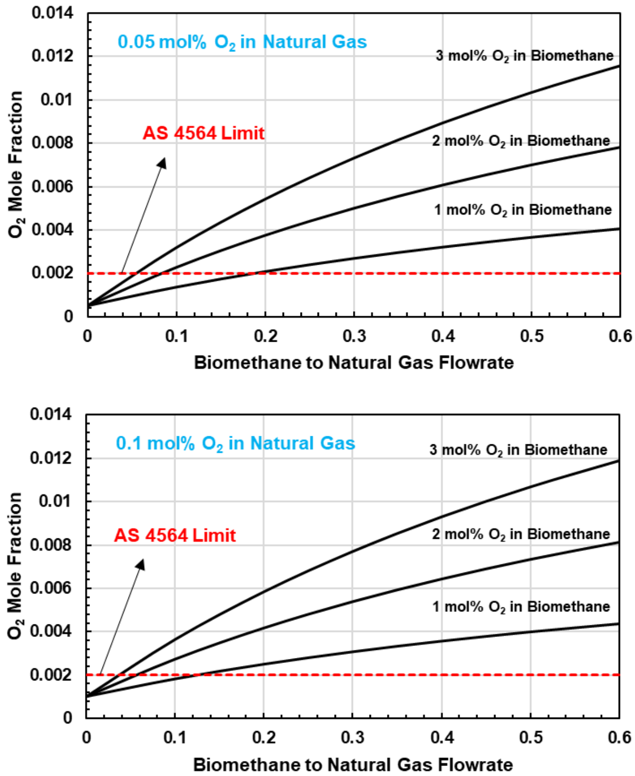

Figure 8. Mixing of natural gas and biomethane composed of binary mixtures of O_2 and CH_4. The red dashed line represents the threshold below which gas mixing compliant with AS 4564 can be achieved.

Mixing calculations for binary mixtures of N_2 as representative of the total inert gas concentration and CH_4 were undertaken. The natural gas concentrations of N_2 were set to 5 mol% and 6.5 mol% (CH_4 balanced). The concentration of N_2 in biomethane was varied from 8 to 10 mol% (CH_4 balance) (Figure 9). Injecting biomethane with 8 mol% N_2 into natural gas with 6.5 mol% N_2 would give a compliant mixed gas at a biomethane to natural gas flowrate ratio of < 42%. Compliance would also be achieved with 9 and 10 mol% N_2 in biomethane at the same natural gas composition, but lower flowrate ratios. Reducing the natural gas concentration of N_2 to 5 mol% would result in compliant mixed gas at all biomethane to natural gas flowrate ratios used in these simulations. Wobbe Index would also lie above the minimum value of AS 4564 for all conditions tested with 5 mol% N_2 in the natural gas (Figure 10) but only some flowrate ratios for 6.5 mol% N_2 in the natural gas supply.

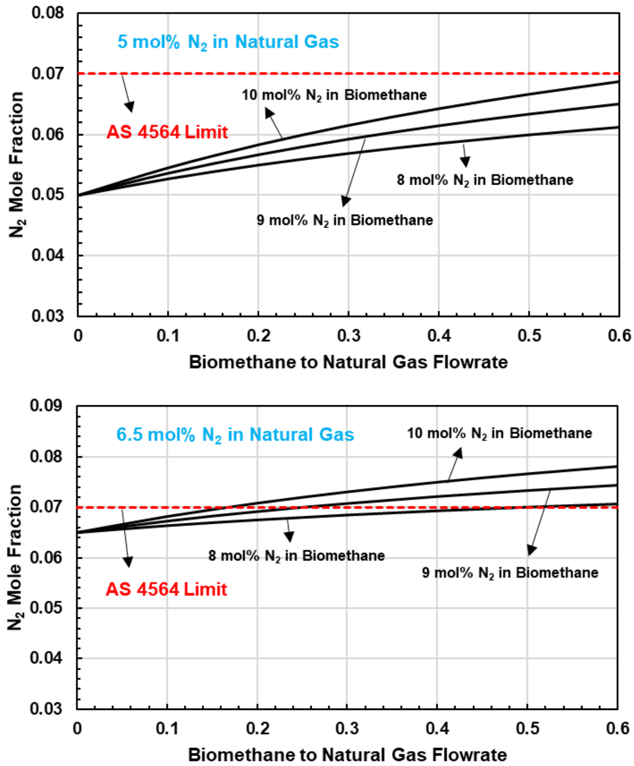

Figure 9. Mixing of natural gas and biomethane composed of binary mixtures of N_2 and CH_4. The red dashed line represents the threshold below which gas mixing compliant with AS 4564 would be achieved.

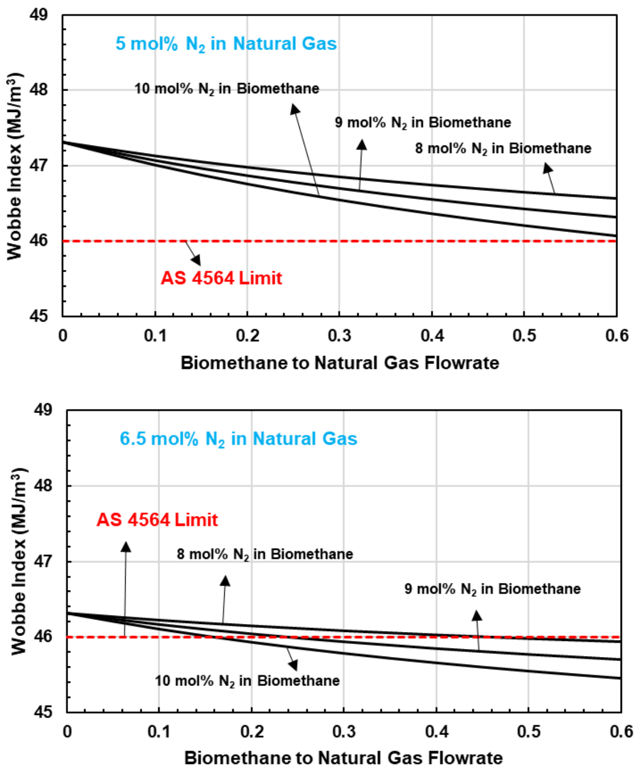

Figure 10. Mixing of natural gas and biomethane composed of binary mixtures of N_2 and CH_4. The red dashed line represents the threshold above which gas mixing compliant with AS 4564 would be achieved.

7 CONCLUSIONS

Major conclusions from this work include:

- Existing state-by-state legislation contains regulatory requirements that can be extended to biomethane injection into natural gas grids. A potential pathway that may enable biomethane injection are through **seeking exemption from authorities and amending safety and operating plans and safety management systems** for pipeline operation.

- An amended safety and operating plan may be comprised of **risk assessment**, **biomethane feedstock monitoring, biomethane gas quality monitoring, downstream gas quality monitoring** and **outputs from CFD studies** on biomethane blending into natural gas.

- The major outcome of the CFD studies presented here is that the biomethane-blended natural gas becomes close to **fully mixed within 20 m from the injection point**, with less than 5% change in the concentrations of the gas constituents compared to the average. This means that if the average composition of the mixture is within AS 4564 limits, this should be delivered to end-users further away. Results also confirmed that close to fully-mixed flow is also achieved when a raw biogas composed of large quantities of contaminants is mixed with the natural gas.

- Knowing that the mixing of biomethane and natural gas would become fully mixed upon reaching end-use customers, mass balance calculations can be used to estimate the final specification of the mixed gas. Calculations show that compliant blending should be possible in many circumstances.

8 REFERENCES

[1] E. Macario, S. Kentish, Literature Review Biomethane Impurities, The University of Melbourne, 2021.

[2] M. Brown, T. Illson, S. Kimpton, Review of Oxygen Specification for the below 7 bar Distribution Network, GL Industrial Services UK Ltd, 2009.

[3] D. Dessanti, K. Crippen, Interconnect Guide for Renewable Natural Gas (RNG) in New York State, Gas Technology Institute, 2019.

[4] S.A. Culley, A.C. Zecchin, H.R. Maier, Summary of the national scale assessment of viable bio-methane locations in Australia, The University of Adelaide, 2022.

[5] Southern California Gas Company (SoCalGas), Renewable Natural Gas Tool Kit, (2021).

[6] D. Saber, K. Cruz, Pipeline quality biomethane: North American guidance document for the introduction of dairy waste-derived biomethane into existing natural gas networks: Tasks 2, Gas Technology Institute, Des Plaines Illinois, 2009.

APPENDIX A: RELEVANT TEXT FROM GAS QUALITY REGULATIONS

State	Acts/Laws/Regulations	As-written Legislative Gas Quality Compliance Requirements
NSW	National Gas Law No. 31a	**Clause 91BRG**: An STTM trading participant must not supply natural gas to an STTM hub that does not comply with the gas quality specifications specified in the Rules for that STTM hub.
	Gas Supply Act 1996 No. 38	**Clause 34: Prohibition of unlicensed distribution of LPG and other gases** A person must not operate a distribution system for the purpose of conveying to any other person: (a) liquefied petroleum gas, or (b) any other gas (other than natural gas) prescribed by the regulations for the purposes of this section, otherwise than under the authority of a distributor's license.
	Gas Supply (Safety and Network Management) Regulation 2013	**Clause 6: Network operators to ensure safe gas supply** (1) A network operator must develop, maintain and operate a safe gas network. (2) A network operator must, when designing, constructing, operating or extending a gas network or any part of a gas network, take into account any standards (such as codes, Australian Standards, guidelines or other requirements) that have been notified in writing to the network operator by the Secretary for the purposes of this subclause.
		Clause 11: Network operators to lodge and implement safety and operating plans (4) A network operator must not construct, alter, extend, maintain, repair or operate a gas network except in accordance with— (a) a safety and operating plan, or (b) a draft safety and operating plan (being a plan that complies with the requirements of this Regulation relating to the form and content, and review and availability, of safety and operating plans but which has not yet been audited in accordance with clause 15) that has been lodged with the Secretary.

State	Acts/Laws/Regulations	As-written Legislative Gas Quality Compliance Requirements
NSW	Gas Supply (Safety and Network Management) Regulation 2013	**Clause 13: Matters to be included in safety and operating plans** (1) The object of a safety and operating plan is to ensure the safe operation of the gas network to which it relates, having regard to a range of matters including gas quality, operating personnel, plant, equipment, the community and the environment. (2) A safety and operating plan must include (but is not limited to) the following matters in relation to each distribution district of the network operator— (d) the gas quality standards to be applied and the procedures to be implemented to ensure that the gas conveyed or supplied meets those standards, (4) A safety and operating plan must comply with **Schedule 1.**
		The regulations associated with the gas quality in Schedule 1 are indicated below: **Schedule 1 Safety and operating plans: 5 Gas quality** The gas quality standards to be applied must include standards relating to the following— (a) heating value, (b) relative density, (c) composition and purity. **Schedule 1 Safety and operating plans: 6 Procedures for ensuring that gas is malodorous** A safety and operating plan must— (a) identify the procedures to be implemented by the network operator to ensure that gas conveyed or supplied has a distinctive and unpleasant odour, and (b) specify the odoriferous substances to be used, and (c) specify the odour intensities. **Schedule 1 Safety and operating plans: 7 Procedures for testing gas** (1) A safety and operating plan must identify the procedures to be implemented by the network operator to ensure that gas conveyed or supplied— (a) meets the relevant gas quality and pressure standards, and (b) complies with the relevant gas specification.

State	Acts/Laws/Regulations	As-written Legislative Gas Quality Compliance Requirements
NSW	Gas Supply (Safety and Network Management) Regulation 2013	**<u>Schedule 1 Safety and operating plans: 10 Codes and standards</u>** If a network operator has departed from any standards that it was required to take into account under clause 6 (2) of this Regulation when designing, constructing, operating or extending its gas network, or any part of its gas network, the safety and operating plan must contain an explanation of— (a) the extent of the departure, and (b) the arrangements in place to ensure that an equivalent or safer outcome has been achieved despite that departure.
		Clause 23: Natural gas in pipelines to comply with standards (1) A reticulator must not convey non-compliant natural gas through a distribution pipeline. (2) A retailer must not supply non-compliant natural gas to an end user customer through a distribution pipeline. (3) A person must not inject non-compliant natural gas, or cause such gas to be injected, into a distribution pipeline.
		Clause 24: Exception from natural gas standards in special cases (1) A reticulator does not commit an offence under clause 23 (1) by conveying non-compliant natural gas through a distribution pipeline if the gas is conveyed in accordance with this clause. (b) the reticulator reasonably believes that the gas that is, or is to be, delivered to the end user customer is compliant natural gas.
		Clause 26: Testing of natural gas (1) A reticulator must not convey natural gas through a distribution pipeline unless the reticulator has tested the gas, or caused the gas to be tested, in accordance with the reticulator's safety and operating plan, to ascertain whether the gas is compliant natural gas.

State	Acts/Laws/Regulations	As-written Legislative Gas Quality Compliance Requirements
NSW	Gas Supply (Safety and Network Management) Regulation 2013	**Clause 30: Natural gas must have odour** A reticulator must ensure that natural gas being conveyed, or to be conveyed, through the reticulator's distribution pipeline has a distinctive and unpleasant odour that is discernible at a level specified in the reticulator's safety and operating plan.
VIC	Gas Industry Act 2001	**Clause 22:** Offence to distribute or retail gas without licence (1) A person must not provide services (other than the sale of gas by retail) by means of a distribution pipeline, either as principal or agent, unless the person— (a) is the holder of a licence authorising that person to provide those services; or (b) is exempt from the requirement to obtain a licence in respect of those services because of an Order under section 24.
		Clause 29: Specific licence conditions Without limiting the generality of section 28, the conditions on a licence may include provisions— (c) requiring the licensee to observe specified Orders in Council, industry codes, standards, rules and guidelines with such modifications or exemptions as may be specified by the Commission;
		Clause 31: Condition specifying industry codes, standards, rules or guidelines (1) If a licence is subject to a condition of a kind referred to in section 29(c), the Commission— (a) may, in accordance with procedures specified by the Commission, amend the specified industry codes, standards, rules or guidelines, or a document referred to in any of them, for the purposes of their application under the licence;

State	Acts/Laws/Regulations	As-written Legislative Gas Quality Compliance Requirements
VIC	Gas Safety Act 1997	**Clause 33: Gas quality** (1) A gas company must ensure that, as far as practicable, the gas which it conveys— (a) meets the prescribed standards of quality; and (b) complies with any other prescribed requirements. (2) A gas company which supplies or sells gas to a customer for use in a gas installation must ensure that, as far as practicable, the gas supplied or sold— (a) meets the prescribed standards of quality; and (b) complies with any other prescribed requirements.
	Gas Safety (Safety Case) Regulations 2018	**Clause 16: Quality of gas supplied to customers** The safety management system must specify the means by which the gas company ensures that it meets its duties under section 33 of the Act.
		Clause 45: Standards of quality—quality of gas For the purposes of section 33(1) and (2) of the Act— (a) the prescribed standard of quality for natural gas conveyed through a transmission pipeline or a distribution pipeline is set out in AS 4564; and (b) the prescribed standard of quality for the supply or sale of natural gas supplied to a customer is set out in AS 4564; and (c) the prescribed standard of quality for LP Gas supplied or sold to a customer for use in an appliance (other than LP Gas used or intended to be used for automotive purposes) is set out in AS 4670. Note: LP Gas means commercial butane or commercial propane that is intended for use in an appliance.
		Clause 46: Standards of quality—odour (1) For the purposes of section 33(1) and (2) of the Act, it is a prescribed standard of quality that all gas must— (a) have an odour which is distinctive and unpleasant; and (b) have an odour level that is discernible at one-fifth of the lower explosive limit of the gas.

State	Acts/Laws/Regulations	As-written Legislative Gas Quality Compliance Requirements
VIC	Gas Safety (Safety Case) Regulations 2018	**Clause 50: Exemptions** (1) Energy Safe Victoria, on the application of a gas company or a manufacturer or operator referred to in Part 3 of the Act, may— (a) exempt a safety case from any of the requirements of these Regulations; or (b) in the case of an application from a gas company for an exemption from compliance with a prescribed standard of quality specified in regulation 45 or 46, grant the exemption if the gas company satisfies Energy Safe Victoria that the conveyance, supply, sale, or use of the gas to which the standard of quality relates will be safe in the circumstances. Note: The Act refers to Gas Safety Act 1997
QLD	Petroleum and Gas (Production and Safety) Act 2004	**Clause 620: Prescribed quality** (1) A regulation may prescribe a quality for fuel gas to be supplied to consumers (***the prescribed quality***). (2) The prescribed quality may be for the purity, composition or physical parameters of the gas. Examples of physical parameters—specific gravity and heating value Note: **Fuel gas** is— (a) LPG; or (b) processed natural gas; or (c) another substance prescribed under a regulation that is similar to LPG or processed natural gas.

State	Acts/Laws/Regulations	As-written Legislative Gas Quality Compliance Requirements
QLD	Petroleum and Gas (Production and Safety) Act 2004	**Clause 621: Restrictions on supplying gas not of prescribed quality** (1) This section applies if a person (the supplier) proposes to supply fuel gas to someone else (the recipient) if— (a) the gas is not of the prescribed quality; and (b) a gas quality approval for the gas is not in force. (2) The supplier must not supply the fuel gas to the recipient, unless— (a) the recipient has agreed in writing to the supply; and (b) the agreement— (i) states that the gas is not of the prescribed quality; and (ii) describes the quality of the gas; and (c) the chief inspector has received the agreement, or a copy of it. (3) An agreement that complies with subsection (2)(a) to (c) is a ***gas quality agreement***
		Clause 622: Chief inspector's power to approve quality (1) The chief inspector may, on the chief inspector's own initiative or on application, approve the quality of fuel gas (a ***gas quality approval***).
		Clause 623: Criteria for approval The chief inspector may issue a gas quality approval only if satisfied— (a) the quality of the gas is acceptable for supply to the relevant consumers; and (b) either— (i) the approval is necessary to ensure sufficiency of gas supply to the relevant consumers; or (ii) that stopping the supply to allow gas of the prescribed quality to be supplied is impractical or may cause a dangerous situation; or (iii) it is impractical to seek the written approval of the relevant consumers to be supplied with gas of that quality.

State	Acts/Laws/Regulations	As-written Legislative Gas Quality Compliance Requirements
QLD	Petroleum and Gas (Production and Safety) Act 2004	**Clause 626: Fuel gas supplied through pipeline** (1) A person who supplies fuel gas must ensure the gas is reasonably free of— (a) any liquids; or (b) substances that are toxic to persons or corrosive to pipelines, gas systems or gas containers. (2) For subsection (1), fuel gas is taken to be reasonably free of liquids or substances mentioned in subsection (1)(b) if they are no more than any level declared under a safety requirement. (4) Subsection (1) applies even if the gas is of the prescribed quality or of a quality approved under a gas quality approval or provided for under a gas quality agreement.
		Clause 627: Prescribed odour A regulation may prescribe a distinctive odour for fuel gas (the ***prescribed odour***) to be supplied for consumer use.
		Clause 628: 628 Odour requirement (1) A person must not supply fuel gas to a consumer unless— (a) the gas has the prescribed odour; or (b) the supply is to an industrial installation with appropriate gas detectors and shut-down systems and a risk analysis has been carried out by an appropriately qualified person showing the supply is safe.
	Petroleum and Gas (Safety) Regulation 2018	**Clause 72: Prescribed quality for fuel gas** (1) For section 620(1) of the Act, the prescribed quality is— (b) for processed natural gas—the quality required to comply with AS 4564 ‘Specification for general purpose natural gas’.
		Clause 73: Prescribed odour for fuel gas (1) For section 627 of the Act, the prescribed odour is an odour that— (a) is distinct, unpleasant and non-persistent; and (b) is of an intensity indicating the presence of gas down to one-fifth of the lower flammability limit; Note: The Act refers to Petroleum and Gas (Production and Safety) Act 2004

State	Acts/Laws/Regulations	As-written Legislative Gas Quality Compliance Requirements
SA	National Gas (South Australia) Act	**Clause 91BRG:** An STTM trading participant must not supply natural gas to an STTM hub that does not comply with the gas quality specifications specified in the Rules for that STTM hub.
	Gas Act 1997	**Clause 26A: Licences authorising retailing** (2) The Commission must make a licence authorising the retailing of gas subject to conditions determined by the Commission— (a) requiring compliance with the relevant parts of the National Gas Procedures (South Australia);
		Clause 59A: Compliance with certain code provisions under *Essential Services Commission Act 2002* and requirements of regulations (1) A NERL retailer must comply with— (a) code provisions as in force from time to time under the *Essential Services Commission Act 2002* specified in, or in a manner prescribed by, the regulations; and (b) any requirements imposed under the regulations, relating to— (d) obligations as to the quality, safety and reliability of the supply of gas (relevant to the supply of gas by retail);
	Gas Regulations 2012	**Clause 38: Obligations of distribution system operator and other persons in relation to quality of gas** (1) A distribution system operator must ensure that the following requirements are complied with in relation to gas distributed by the system: (a) the gas must— (i) be at a safe temperature and pressure and safe in all other respects for the purposes of the system; and (ii) contain sufficient odorant that it has a distinctive smell to a person with a normal sense of smell at one-fifth of the lower explosive limit in air; and (iii) comply with the relevant specifications set out in **Schedule 2** (unless otherwise agreed between the Technical Regulator and the operator);

State	Acts/Laws/Regulations	As-written Legislative Gas Quality Compliance Requirements
SA	Gas Regulations 2012	**<u>Schedule 2—Gas specifications</u>** (regulations 38 and 40) 1—Specifications for natural gas The specifications for natural gas are the limits set out in AS 4564 for general purpose natural gas (within the meaning of that Standard). 2—Specifications for liquefied petroleum gas The specifications for liquefied petroleum gas are as follows: (a) it must contain less than 12 mg/m3 of hydrogen sulphide; (b) its combustion characteristics must not be more than 10% above or 10% below the limits of— (i) the Wobbe Index; and (ii) the flame speed factor; and (iii) the sooting index, as derived from Test Gas X referred to in the Test Gas Table set out in the Australian gas appliance standards listed in AS 3645. 3—Specifications for other gas The specifications for gas other than natural gas or liquefied petroleum gas are as follows: (a) it must contain less than 12 mg/m3 of hydrogen sulphide; (b) its combustion characteristics must not be more than 10% above or 10% below the limits of— (i) the Wobbe Index; and (ii) the flame speed factor; and (iii) the sooting index, as derived from the test gases for the type of gas referred to in the Test Gas Table set out in the Australian gas appliance standards listed in AS 3645.
		Clause 52: Technical Regulator may grant exemption from Part 9 or this Part (1) The Technical Regulator may grant an exemption from a specified provision or provisions of Part 9 or this Part on terms and conditions the Technical Regulator considers appropriate. (2) An exemption under subregulation (1) may be varied or revoked by the Technical Regulator by notice in writing. Note: Part 9 makes provisions for gas quality as stated in Clause 38.

Future Fuels CRC

Enabling the Decarbonisation of Australia's Energy Networks

www.futurefuelscrc.com

info@futurefuelscrc.com

Australian Government
Department of Industry, Science, Energy and Resources

Business
Cooperative Research Centres Program