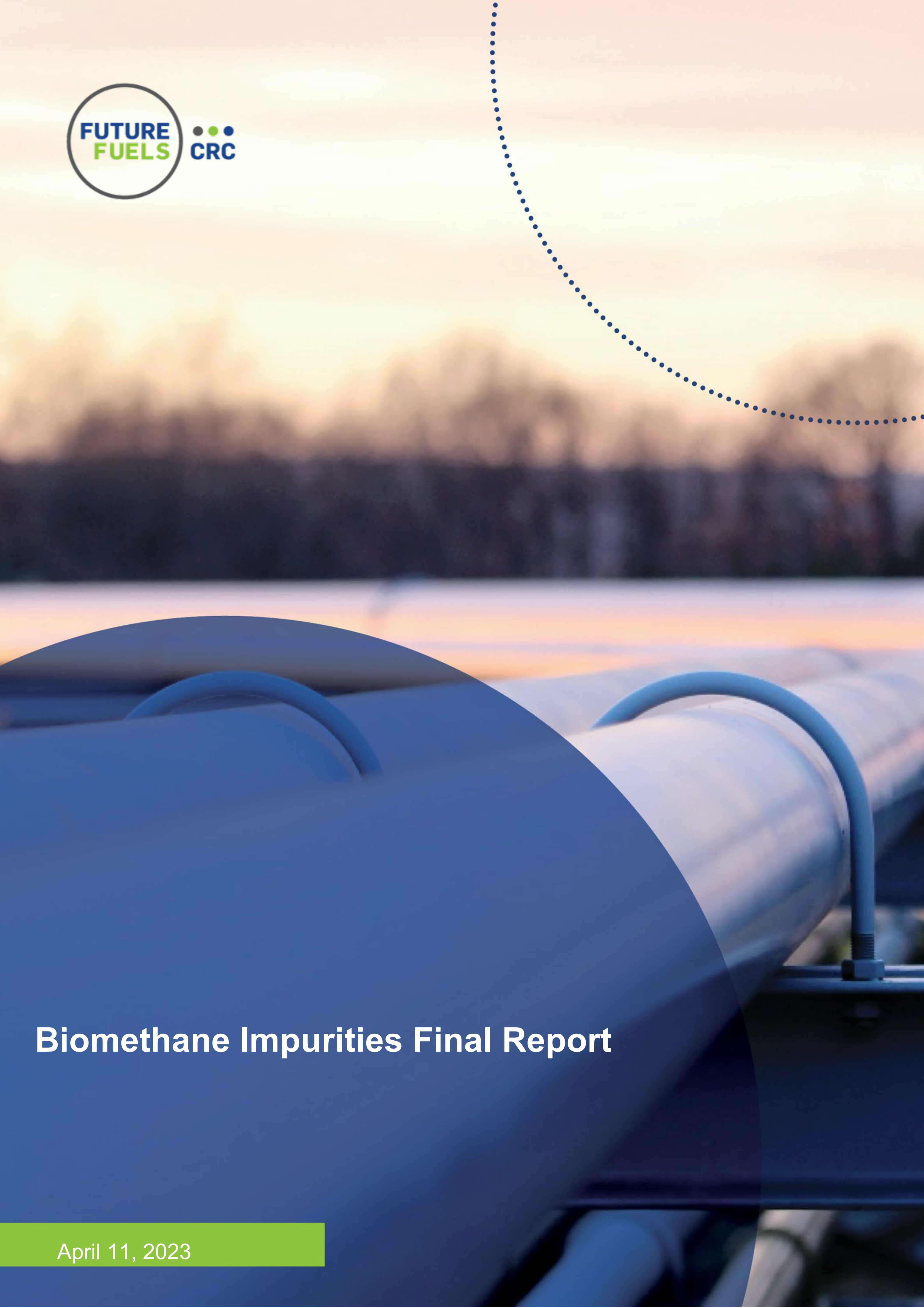

Biomethane Impurities Final Report

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IMPORTANT DISCLAIMER

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PROJECT INFORMATION	
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Milestone Number	6
Description	Final Report
Research Provider	The University of Melbourne
Project Leader and Team	Sandra Kentish, Colin Scholes, Amanda Ellis, Ehsan Soroodan Miandoab, Erwin Macario, Holger Maier, Sam Culley
Industry Proponent and Advisor Team	Siew Shan Foo, Shreyas Rajpurkar, Huw Evans, Christopher Larkin, James McHugh, Xiaoda Xu, Justin Brown
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Contents

1 PROJECT OVERVIEW

This report is the final deliverable for the Future Fuels Cooperative Research Centre (FFCRC) Project RP3.2-09.

This project aimed to establish regulatory quality requirements for biomethane injection into Australian gas networks. A clear collection of biomethane quality standards can provide pipeline operators, end-users and biomethane project developers with a clear understanding of quality obligations, alongside operational and cost responsibilities. The overall project purpose is to improve industry confidence in biomethane injection, leading to increased market participation.

The study provided a detailed list of contaminants of concern with quantified allowable limits based on a comprehensive literature review. It further presented methodologies for biomethane injection pathways in compliance with Australian Standard AS 4564 and state-by-state legislative requirements.

The work has been delivered through a sequence of reports and an industry workshop, each of which are summarised below.

1.1 FIRST REPORT (DELIVERABLE 2): LITERATURE REVIEW REPORT AND ELECTRONIC DATABASE OF BIOMETHANE CONTAMINANTS

The technical and economic feasibility of biomethane injection into natural gas networks is evident from its widespread implementation across the world, particularly in European jurisdictions. This review utilised the wide existing body of work, including existing regulatory requirements, in combination with published academic literature, to perform the two tasks:

- Assessment of quality considerations needed to safely implement biomethane injection into the Australian gas grid.
- Determination of high-priority experimental studies to facilitate the implementation of proposed quality considerations.

The above tasks were conducted via a review of commercially utilised biomethane feedstocks and upgrading processes, followed by quantitative and holistic analysis of parameters and contaminants of concern for biomethane injection. This was performed in combination with a review of all regulatory biomethane quality requirements for all countries with > 5 operating biomethane upgrading facilities, leading to an analysis of 17 different countries / jurisdictions. This resulted in a comprehensive list of biomethane parameters to be used as inputs for future Australian biomethane quality regulations.

1.1.1 Analysis of Biomethane quality parameters and contaminants for grid injection

To support the task of determining appropriate biomethane quality regulations, identified parameters were divided into two classifications; those that already possessed existing limit values in AS 4564 (e.g., Wobbe Index, oxygen content) and those that did not (e.g., ammonia, siloxanes). The existing AS 4564 quality requirements were assessed for their suitability for biomethane injection, with a view to determine the feasibility of relaxing existing quality requirements to promote biomethane production. Examination of AS 4564 found three potential avenues for improving the viability of biomethane production, via the relaxation of the minimum and maximum Wobbe Index and oxygen / total inerts concentrations, respectively. These initiatives are based on similar efforts found in other biomethane producing jurisdictions examined, which could be emulated for Australian biomethane production.

The second class of parameters were assessed to provide Australian decision makers with information to determine the appropriate limit values for biomethane quality for Australian pipelines. To assist with this process, the literature was reviewed for quantitative concentration values in biogas / biomethane, along with existing regulatory information as summarised in **Table 1 (overleaf)**. This information was combined with analysis of the integrity and health-based detrimental effects associated with each parameter, and the effectiveness of biomethane upgrading methods in removing said parameter, to inform Australian decision makers.

Table 1 Biomethane Parameters / Contaminants without AS 4564 Limits

Parameters / Contaminants	Biogas Range	Biomethane Range	Regulatory Coverage[1]	Limit Value Range[2]
Hydrogen	BDL[3]	BDL – 0.9 mol. %	9/13	0.1 – 5.0 mol %
Siloxanes	BDL – 14.4 mgSi/m^3 (8000 mg/m^3)[4]	BDL – 0.4 mgSi/m^3	9/13	0.01 – 10 mg Si/m^3
Ammonia	0.2 – 63 mg/m^3	0.15 – 0.25 mg/m^3	8/13	3 – 20 mg/m^3
Halocarbons	BDL – 735 mgCl/m^3	BDL	7/13	1 – 10 mg (Cl/F)/m^3
Semi-Volatile and Volatile Organic Compounds (SVOCs and VOCs)	10 – 700 mg/m^3	<1 – 100 mg/m^3	3/13	< 100 mg/m^3 Xylene (UK) < 904 mg/m^3 Toluene (California, USA) < 3.7 ppm General VOC contents (Quebec, Canada)
Heavy Metals	**Mercury:** BDL – 0.02 µg/m^3 **Arsenic:** BDL - 8.5 µg/m^3	**Mercury:** BDL – 0.05 µg/m^3 **Arsenic:** BDL – 0.32 µg/m^3	2/13	< 1 µg/m^3 Mercury limit recommendation in AS 4564 is sufficient. 19 – 30 µg/m^3 Arsenic 30 – 60 µg/m^3 Copper 600 µg/m^3 Antimony (California, USA) 75 µg/m^3 Lead (California, USA)
Bacteria[5]	**APB**[6]**:** 1.23 x 10^3 – 6.03 x 10^4 **IOB**[5]**:** 1.02 x 10^3 – 5.09 x 10^3 **SRB**[5]**:** 1.1 x 10^2	**APB:** 9.69 x 10^1 – 2.02 x 10^5 **IOB:** 6.9 x 10^2 – 7.67 x 10^4 **SRB:** 1.65 x 10^2 – 2.52 x 10^4	1/13	4 x 10^4 CFU/scf (qPCR per APB, SRB, IOB group) and commercially free of bacteria of >0.2 microns (California, USA)
Pesticides	Note 1	Note 1	0/13	N/A
Pharmaceuticals	Note 1	Note 1	0/13	N/A
Phosphine	Note 2	Note 2	0/13	N/A

Notes:

[1] Number of jurisdictions with gas quality regulations for each parameter / contaminant. Only 13 out of 18 jurisdictions were found to have unique biomethane quality regulations.
[2] Range of maximum contaminant limits found via the regulatory review.
[3] BDL = Below Detection Limits.
[4] Total siloxane concentrations of up to 8,000 mg/m^3 have been reported for raw landfill gas.
[5] Concentrations presented in Colony Forming Units (CFU)/100 scf.
[6] APB, IOB, SRB = Acid Producing Bacteria, Iron Oxidising Bacteria, Sulphate Reducing Bacteria.

1. All reports of pesticide and pharmaceutical detection were either at concentrations BDL or orders of magnitude lower than recommended exposure limit concentrations.
2. No quantitative information could be found for phosphine contents in biogas / biomethane.

1.1.2 Summary of Regulatory Approaches for BIomethane Injection

The review of the various regulatory approaches for managing biomethane injection quality while promoting industry growth revealed several ideas that could be implemented in the management of Australian biomethane injection. One of the common approaches relies on feedstock-based testing requirements, due to the intrinsic relationship between certain feedstocks and the presence of adverse contaminants. The relationship between feedstocks and contaminants, alongside proposed testing schemes, are covered in detail within this report.

Other regulatory schemes that aim to promote the distribution of biomethane come in the form of allowances for pipeline blending for non-compliant biomethane. This was found in several jurisdictions, an example of which is a Swiss scheme that allows non-compliant injection on the basis that the resulting mixed gas is compliant at the first exit point of a consumer. Another detailed gas blending scheme incorporated into existing regulations is one conducted by the Californian Council on Science and Technology, which states that pipeline blending must be evaluated on a case-by-case basis. This was also found to be the approach of German legislature, which also allowed pipeline blending subject to conditions of the local gas network.

1.2 INDUSTRY WORKSHOP (DELIVERABLE 3)

The workshop was held online on 20th July 2021. It was attended by 22 stakeholders from 13 industry / regulatory organisations. Critical project topics identified via input from the wide range of stakeholders present were:

I. Oxygen was identified as one of the most important impurities affecting project economics.

II. There was an emphasis on an “enable all” approach for providing guidance on how developers may comply with Australian biomethane quality requirements

III. There was an experience-based consensus established that higher O_2 limits (up to 1 mol %) are unlikely to lead to flame abnormalities in Type A appliances, however a testing program utilising higher O_2 concentrations was still recommended. Note that this testing program was included within Project RP1.4-07 (Biomethane injection into the gas network: impact of impurities on the performance of end-use appliances).

1.3 SECOND REPORT (DELIVERABLE 4): A METHODOLOGY DOCUMENT DETAILING BIOMETHANE TESTING AND INJECTION PATHWAYS TO MEET EXISTING AUSTRALIAN STANDARDS AND REGULATORY REQUIREMENTS

This report aimed 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 (see Appendix A). 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 (see Appendix

B). 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 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. 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.

1.4 THIRD REPORT (DELIVERABLE 5): DESKTOP REVIEW AND CORROSION MODELLING FOR INTEGRITY-BASED IMPACTS OF RAISING AS-4564 OXYGEN LIMITS ON AUSTRALIAN NATURAL GAS NETWORKS

This report aimed to provide insight into the corrosion of natural gas pipelines after injecting biomethane with oxygen (O_2) concentrations greater than the AS 4564 allowable limit, i.e. 0.2 mol%. Corrosion rate calculations are performed by two approaches: a theoretical method simulated by FREECORP software, and an empirical model developed from experimental data. Key conclusions from the corrosion modelling are summarized as follows:

- The mechanism of corrosion in natural gas pipelines shows that O_2-induced corrosion requires liquid water to take place.
- If such free water is present, the increase in corrosion rate is approximately linearly proportional to the increase in oxygen partial pressure. This means doubling the oxygen concentration would likely double the internal corrosion rate in any existing asset.
- The corrosion rate increases with CO_2 partial pressure but the increase is less pronounced than that of O_2.
- The corrosion rate increases with the velocity of the aqueous phase, which may move more slowly than the bulk gas flow.
- The effect of temperature on the corrosion rate is also linear and stronger than CO_2 partial pressure.
- the most vulnerable assets are those operating under high total gas pressures and with a possibility of free water to be present.

1.4.1 Recommendation

Based on an analysis of international practice, it is recommended that Australian guidelines and/or regulations take a nuanced approach to the allowable oxygen levels in pipeline networks, as has been done in the UK and Europe. Specifically, it is recommended that a new NOTE be added to Table 4.1 in AS4564 as follows:

NOTE 6 Higher oxygen concentrations (up to 3%) may be permissible if appropriate validation of downstream assets and infrastructure permits. In such cases, additional risk mitigation actions may be required and should be discussed with the relevant regulatory authority. See Appendix A3.4.

With Appendix A3.4 expanded to read:

Internal corrosion of pipeline infrastructure is exacerbated by high partial pressures of oxygen. Such corrosion will occur if water is present as a free liquid, adsorbed to hygroscopic salt deposits or absorbed in liquid glycol carried over from dehydration units. Corrosion increases with temperature and in the presence of acidic gases (carbon dioxide and hydrogen sulfide).

APPENDIX A 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

APPENDIX B 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.

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