# CODE OF OPERATIONS MODIFICATION PROPOSAL

| MODIFICATION DETAILS | | | | |
|---|---|---|---|---|
| **Modification Number**: A111 | **Modification Title:** Amendment to Code of Operations to increase oxygen limit for biomethane entry points on the transmission network | | | |
| **Modification Proposer:** | **Modification Representative:** | **Modification Representative Contact Details (email address):** | **Date Submitted**: | **Proposed Implementation Date:** |
| Gas Networks Ireland | Yvette Jones | yvette.jones@gasnetworks.ie | 15 June 2023 | TBD |

**Proposal (including rationale):**

To allow transmission network connected biomethane entry points to inject biomethane into the transmission network with a maximum upper limit for oxygen of up to and including 0.5 mol%.

Biomethane typically has a higher oxygen content than natural gas and it might not always be feasible for biomethane producers to meet the current oxygen upper limit of 0.2 mol% for transmission entry points.

**Proposed Implementation Date:**

TBD

**Proposed section of the Code to be modified:**

Part G Technical, Appendix One

## MODIFICATION MOTIVATION

**Intended Outcome of the Proposed Modification:**

To allow biomethane entry points on the transmission network, with the approval of the CRU and GNI, to inject gas with a maximum oxygen content of up to and including 0.5 mol%.

**Benefits of implementing this Modification:**

The modification will facilitate the injection of more biomethane into the gas network. This will support the decarbonisation of the gas network (and other sectors) and provide a valuable source of renewable energy for gas customers. Biomethane also has a role to play in Ireland's security of gas supply. It should also be noted that a new limit of ≤ 0.5 mol% is more aligned with the current European network parameters for biomethane oxygen content in similar networks.

**Consequences of not making this Modification:**

If this code modification is not implemented, lesser amounts of renewable gas will be injected into the gas network.

**Regulatory Impact Assessment:**

A number of studies were carried out to assess impacts of increase oxygen on Transmission Network:

- Technical Note SR3452248 Mitchelstown BNEF Analysis January 2021 and Technical Note (SR 4213606) Mitchelstown CGI at 0.5 mol% Oxygen concentration (Gas Networks Ireland)
- CFD Simulations of Biomethane Injection into Gas Network (Dynaflow Research Group)
- Impact on gas turbine power generation of Biomethane addition from Mitchelstown BNEF to the Irish gas network (Uniper)
- "Biomethane – 1.0 mol% Oxygen Content Assessment" (Penspen)

**Illustrative Example (Please enter a scenario where the issue and solution are illustrated):**

If a biomethane producer's gas does not meet the current oxygen upper limit of 0.2 mol%, it would not be permitted to be injected into the gas network. This will result in less renewable energy being made available to end users and financial loss for the producer.

**EXPLANATORY MEMORANDUM**

**Code Modification Proposal A111 - Amendment to Code of Operations to increase oxygen limit for biomethane Entry Points on the transmission network**

**Background**

The Code of Operations (the "Code"), Part G, Appendix One, provides that Entry Points on the transmission network cannot inject gas with an oxygen content of more than 0.2 mol%. Appendix One was amended in 2018 to provide that the oxygen content for biomethane at an Entry Point connected to the Distribution System can be up to 1 mol% (previously the upper limit on Distribution System for all Entry Points was also 0.2 mol%) where there is provision for automatic discontinuation of gas flows for non-compliance with the applicable Entry Specification. This change to the Code of Operations was made in 2018 following a study carried out on behalf of Gas Networks Ireland (GNI). The change was required to support the injection of biomethane into the gas distribution network. The distribution network consists mostly of polyethylene pipelines and steel pipelines operating at maximum allowable operating pressures of 4 barg and 7 barg respectively. In the UK the HSE has permitted the introduction of natural gas containing up to 1 mol% oxygen at pressures of up to 38 barg into the gas distribution network. This permission covers both transmission and distribution networks, however the 38-bar limit would exclude the National Transmission Network.

A modification to the Code of Operations is now required to support the injection of biomethane into the Irish transmission network. While biogas to biomethane upgrading technology and processes are improving, it might not be feasible for biomethane producers to consistently meet the current Code of Operations gas quality specifications of an upper oxygen limit of 0.2 mol%

**The Proposal**

GNI proposes to increase the allowable upper oxygen limit for biomethane injected into the gas Transmission Network up to and including 0.5 mol%. This will require a change to the Code, Part G, Appendix One. It should be noted that a new limit of ≤ 0.5 mol% would be more aligned with the current European network parameters for biomethane oxygen content in similar networks.

Before Transmission Network Renewable Gas Entry Points can avail of this Code Modification GNI must be of the reasonable opinion that an increased oxygen content in respect of RNG delivered, or tendered for delivery, to the Transmission System would not adversely impact the End User operational facilities (save to the extent any potential adverse impact could, in the opinion of the Transporter, be reasonably mitigated by the End User) and would not adversely affect the Transmission System

Renewable Gas Entry Points on the Transmission Network will be considered on a case-by-case basis as the circumstances may differ for individual Entry Points depending on their capacity and location on the Transmission Network.

**The Benefit**

The increased focus on decarbonisation and the impacts of greenhouse gas emissions on our climate and environment, as well as geopolitical developments impacting security of supply and energy prices, requires GNI to provide indigenous renewable gas producers with the facilities to inject renewable gas into our gas network.

An indigenous renewable gas industry in Ireland would support numerous Irish and European policy targets and initiatives. It would also provide significant opportunities and benefits for Ireland, including:

- Significant source of renewable gas for customers
- Contribution to decarbonising the gas network and Irish industries
- Support the agricultural sector with decarbonisation
- Enhanced security of supply
- Prospect of a new indigenous industry with associated job creation
- Enhance the gas industry's image

Biomethane injection into the gas grid is a proven and well-established process/technology; there has been consistent growth in renewable gas injection facilities across Europe. By the end of 2021 there were 1,067 biomethane production facilities across Europe[1].

Ireland has one of the highest potentials per capita in Europe to produce biogas from waste streams[2], primarily due to our large agricultural sector. Studies show that in Ireland there is sufficient capacity from improved efficiency across land already in agricultural production to produce up to 9.5TWh per annum of biomethane without any negative impacts on food production or land use[3]; this would displace ~17% of natural gas in the network (this is considered to be a conservative estimate since the potential opportunities from food waste and tillage crop rotations have not been included in the studies). Despite this, Ireland has one of the lowest penetrations of biomethane production and renewable gas in its gas network in Europe. Currently, there is only one biomethane injection facility in Ireland (Cush, County Kildare).

1 EBA Statistical Report 2022, Tracking biogas and biomethane deployment across Europe.

[2] Commission, "Optimal use of biogas from waste streams An assessment of the potential of biogas from digestion in the EU beyond 2020" (Brussels: December 2016) https://ec.europa.eu/energy/sites/ener/files/documents/ce_delft_3g84_biogas_beyond_2020_final_report.pdf

[3] https://www.gasnetworks.ie/biomethane-sustainability-report-2021.pdf

## Introduction

Gas Networks Ireland (GNI) carried out / commissioned four studies to understand further the impacts on the transmission network of increasing the current upper limit for oxygen content of ≥0.2mol%. This document provides a summary overview of three of the studies, along with the conclusions as determined by the parties who carried out the studies. The fourth study, carried out by Penspen, "Biomethane – 1.0 mol% Oxygen Content Assessment", will be made available in its entirety to interested parties. The other three studies will not be made available in full to protect commercial sensitivities but summary points from the studies are captured in this document below.

The three studies summarised in this document are:

- Technical Note SR3452248 Mitchelstown BNEF Analysis January 2021 and Technical Note (SR 4213606) Mitchelstown CGI at 0.5% Oxygen concentration (Gas Networks Ireland)
- CFD Simulations of Biomethane Injection into Gas Network (Dynaflow Research Group)
- Impact on gas turbine power generation of Biomethane addition from Mitchelstown BNEF to the Irish gas network (Uniper)

## Technical Note SR3452248 Mitchelstown BNEF Analysis January 2021

### *Overview*

This Technical Notes outlines the results of Gas Networks Ireland's network analysis to estimate the penetration of biomethane injected at the Mitchelstown Central Grid Injection (CGI) facility into the transmission network.

Modelling based on several assumptions:

- Injection rate of 5,000 standard cubic metres (scm) per hour and 20,000 scm per hour
    - The injection rates reflect phased delivery of the CGI
- Modelled on transient basis whereby the 24-hour demand cycle over a period of three days was simulated to obtain steady results
- Demands modelled as energy flows
- 15°C assumed the system wide gas temperature
- Scenarios modelled on average winter peak day an Average Winter Peak day and a Summer Minimum Demand day for the 2022/23 and the 2024/25 gas years
- Network operating as per standard configuration

The penetration of the biomethane into the network was assessed by measuring changes at various points on the network between the base case scenarios and the same demand scenarios with the Mitchelstown CGI supply flowing.

*Biomethane Network Penetration*

The figures below depict the percentage of biomethane penetration at various points on the transmission network. In none of the scenarios is biomethane observed on the Cork-Dublin pipeline northeast of Curraleigh West (Rochestown) or travelling west from Corracunna. The majority of the biomethane penetration is in the Cork area with biomethane penetration South of Curraleigh west in all scenarios.

Figure 1 below provides a graphical overview of the biomethane penetration observed in the Average Winter Peak 2022/23 scenario with the Mitchelstown CGI injecting 5,000 scm per hour.

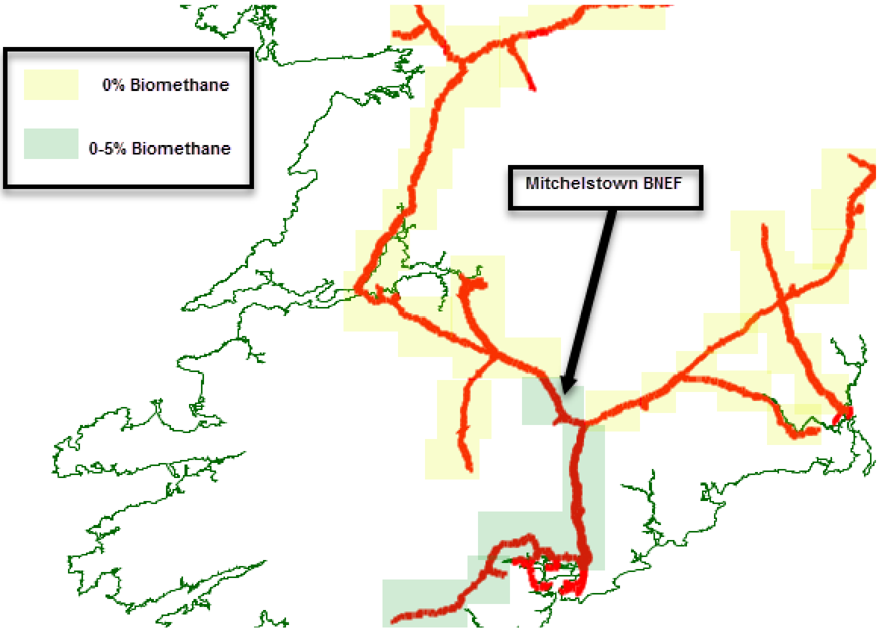



Figure 2 below provides a graphical overview of the biomethane penetration observed for the Summer Minimum Demand Day 2022/23 scenario with the Mitchelstown CGI injecting 5,000 scm per hour.

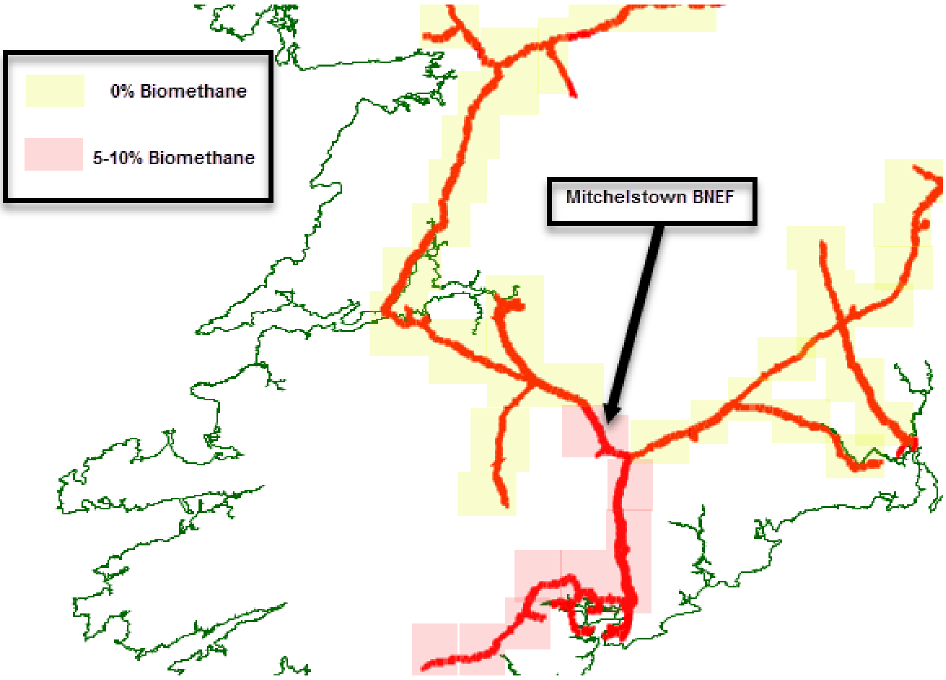


Figure 3 below provides a graphical overview of biomethane penetration observed in the Average Winter Peak 2024/25 Scenario with Mitchelstown CGI injecting 20,000 scm per hour.

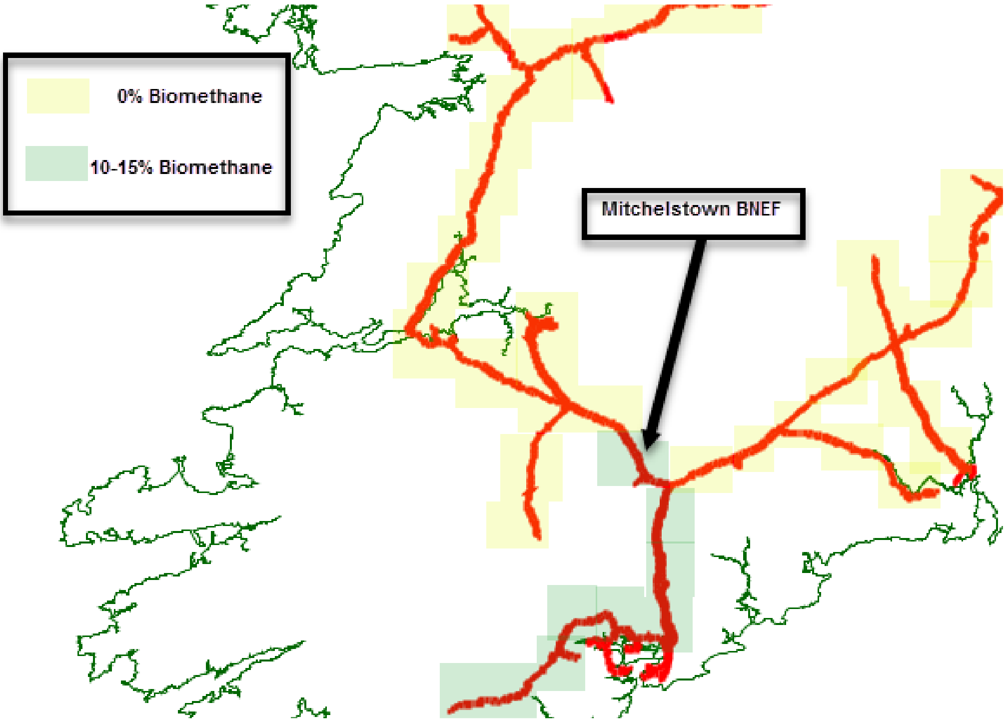
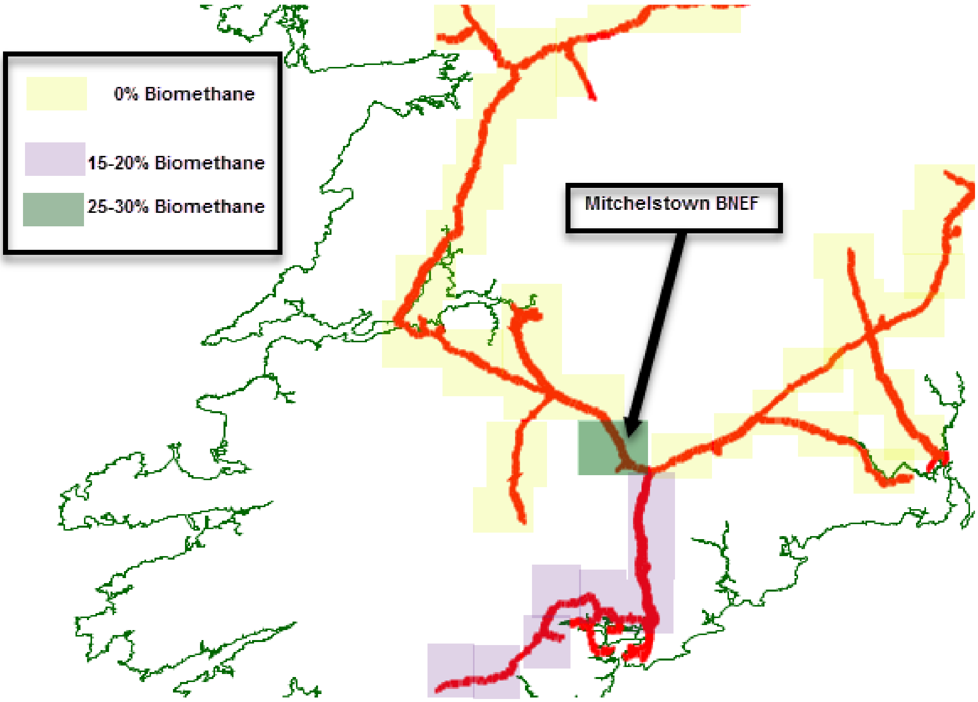



Figure 4 below provides a graphical overview of biomethane penetration observed for the Summer Minimum Demand Day scenario with Mitchelstown CGI injecting 20,000 scm per hour.



*Oxygen Levels*

Table 1 below shows the maximum oxygen levels observed at various locations on the network when biomethane injected at the Mitchelstown CGI having an oxygen content of 1 mol%. There are two locations where the oxygen content would be above 0.2 mol%, the current upper limit for oxygen on the transmission network. Neither of these locations are power stations.

| Location | Average Winter Peak 5k scm/hr | Summer Min Day 5k scm/hr | Average Winter Peak 20k scm/hr | Summer Min Day 20k scm/hr |
|---|---|---|---|---|
| A | 0.022% | 0.0488% | 0.114% | 0.1911% |
| B | 0% | 0% | 0% | 0% |
| C | 0.027% | 0.0508% | 0.1244% | 0.1986% |
| D | 0% | 0% | 0% | 0% |
| E | 0.0325% | 0.0691% | 0.1342% | 0.2522% |
| F | 0.0325% | 0.0691% | 0.1342% | 0.2522% |

*Table 1: Oxygen levels at various network locations*

### *Technical Note (SR 4213606) Mitchelstown CGI at 0.5% Oxygen concentration*

In December 2022 GNI ran the analysis again, this time using a maximum upper oxygen limit of 0.5 mol% for gas entering the network at the Mitchelstown CGI. The maximum oxygen concentration observed at a large end user facility is 0.1656%, which is under the upper limit for oxygen on the transmission network.

GNI's Code Modification Proposal for a new oxygen limit for renewable gas injection facilities connected to the Transmission Network will be for a maximum oxygen content of ≤ 0.5 mol%. Technology improvements for biogas to biomethane upgrading equipment and processes support the production of biomethane with an oxygen content of ≤ 0.5 mol%. It should also be noted that a new limit of ≤ 0.5 mol% is more aligned with the current European network parameters for biomethane oxygen content in similar networks.

## CFD Simulations of Biomethane Injection into Gas Network

In 2021 GNI commission the Dynaflow Research Group to carry out a detailed flow analysis study to demonstrate the effect of mixing biomethane and natural gas at the Mitchelstown CGI facility. For this study the method of Computational Fluid Dynamics (CFD) was used.

To assess the mixing of biomethane with the natural gas in the pipeline a model of the connection point and the main gas pipeline was created. Different flow conditions were evaluated on their impact on the mixing rate of both gases. Analysis was carried out for Average Winter Peak and Summer Min days, as well as 5,000 scm per hour and 20,000 scm per hour flow rates.

The following conclusions were drawn by the Dynaflow Research Group:

- Gas mixed well in all scenarios and no slugging of biomethane was observed
- At low injection rates, compared to the natural gas flow in the header, the biomethane was found to remain concentrated in the branch-side of the pipe at the injection point
- Over the length of the modelled pipe, the gas was found to mix sufficiently well
    - Further length of pipe and bends/fittings will improve the mixing even further at the injection point

- Even with high concentrations of biomethane (58%), mixing found to be sufficient

## Impact on gas turbine power generation of Biomethane addition from Mitchelstown BNEF to the Irish gas network

In 2022 GNI commissioned Uniper to evaluate the potential impact of biomethane addition to the Irish gas network on the operation of gas turbines connected to the grid. For the purposes of this evaluation, it was assumed that the biomethane would contain 1 mol% of oxygen. In the report Uniper concludes that the introduction of biomethane will increase the variation of fuel composition at the power generation sites on the gas network. However, appropriate tuning should maintain any variations within acceptable levels if the range of variation is within that allowed by the manufacturer's specification.

Based on Uniper's interpretation of the manufacturers' specifications for the gas turbine types considered, the range of variation, as predicted by GNI's network analysis for an upper oxygen limit of 1 mol% (Technical Note SR3452248 Mitchelstown BNEF Analysis January 2021), will be within the capabilities of the gas turbines.

Some tuning of the gas turbines may be required to ensure optimum combustion performance over the whole range of fuels, but it should also be noted that wider variations in the base natural gas could occur.

Uniper also concluded that, while there is no reason why levels of oxygen predicted at these sites should directly cause combustion problems, there may be an impact on materials corrosion and degradation.

Although major issues with gas turbine performance due to biomethane addition are not anticipated it would be prudent to have this confirmed by the relevant manufacturers. It would also be advisable to consider whether a wider range of variation in the base natural gas than that used in the evaluation could occur.

It should be noted that while the Uniper report was based on 1 mol% oxygen content for biomethane, GNI's Code Modification Proposal for biomethane injected into the Transmission Network will be for a lesser amount of ≤ 0.5 mol%.

GNI would be happy to have one-to-one discussions with power generation operators, and other stakeholders as appropriate, on the findings of these studies.

# Biomethane – 1.0 mol% Oxygen Content Assessment

20424-AI-RPT-001 Rev 3

Gas Networks Ireland

May 2023

Penspen
4th Floor, Rotterdam House
116 Quayside
Newcastle upon Tyne
NE1 3DY
United Kingdom

Penspen Limited, incorporated in England, registered office: 74 Wigmore Street, London, W1U 2SQ England, reg. no. 0584446



Revision, change control and authorisation history.

| **Document owner:** | *CDE for Materials and Corrosion* | | | | | |
|---|---|---|---|---|---|---|
| **Rev** | **Date** | **Description and/or change history** | **No of pages** | **Prepared**<br>Name<br>Job title | **Checked**<br>Name<br>Job title | **Authorised**<br>Name<br>Job title |
| **0** | **28/03/2022** | **Issued for client review** | **34** | **BGK**<br>**Principal Consultant** | **N L**<br>**Consultant** | **BGK**<br>**Principal Consultant** |
| **1** | **27/04/2022** | **Issued for Use** | **40** | **BGK**<br>**Principal Consultant** | **NL**<br>**Consultant** | **BGK**<br>**Principal Consultant** |
| **2** | **13/01/2023** | **Updated based on Comments and Issued for Use** | **41** | **BGK**<br>**Principal Consultant** | **NL**<br>**Consultant** | **BGK**<br>**Principal Consultant** |
| **3** | **23/05/2023** | **GNI revision** | **41** | **BGK**<br>**Principal Consultant** | **NL**<br>**Consultant** | **BGK**<br>**Principal Consultant** |

# CONTENTS

**Abbreviations 3**

**1 Executive Summary 4**
1.1 Introduction 4
1.2 Conclusions 5
1.3 Recommendations 5

**2 Introduction 7**
2.1 Background 7
2.2 Objective 7
2.3 Scope 7

**3 Asset Details 9**

**4 Methodology 10**

**5 Oxygen Limits in Other European Countries 11**
5.1 European Standards 11
5.2 Oxygen Limits in Individual Countries 12
5.3 Comparison between Gas Networks in Ireland and the UK 14
5.4 Ongoing Initiatives in the UK 15

**6 Calorific Value 17**
6.1 Calorific Value 17

**7 Explosion and Flammability Assessment 18**
7.1 Effect of Concentration 18

**8 Corrosion Review 19**
8.1 Corrosion in Natural Gas Pipelines 19
8.2 Corrosion Models 19
8.3 Previous Studies 22
8.4 Corrosion Rate Calculation 23
8.5 Effect of Partial Pressure of Oxygen 25
8.6 Gas Dryness 25

**9 Impact on End User Equipment 27**
9.1 Factors 27
9.2 Equipment Types 28
9.3 End User Comments 29

**10 Risk Assessment 32**
10.1 ALARP Demonstration 32
10.2 Unmitigated Corrosion Threat 32
10.3 Mitigated Corrosion Threat 33
10.4 GNI Mitigated Control Measures 34

**11 Impact of Proposed Injection of Biomethane at Mitchelstown 35**

**12 Conclusions and Recommendations 37**
12.1 Conclusions 37
12.2 Recommendations 38

**13 References 39**

## ABBREVIATIONS

| | |
|---|---|
| ALARP | As Low As Reasonably Practicable |
| CHP | Combined Heat and Power |
| CRU | Commission for Regulation of Utilities |
| CV | Calorific Value |
| ECE | Electronic Corrosion Engineer |
| ENTSOG | European Network of Transmission System Operators for Gas |
| GNI | Gas Networks Ireland |
| HCDP | Hydrocarbon Dew Point |
| HSE | Health and Safety Executive |
| LEL | Lower Explosive Limit |
| mm/yr | Millimetres per year |
| mpy | mils per year |
| NTS | National Transmission System |
| PE | Polyethylene |
| ppmv | Parts per million (volume) |
| SGN | Scotia Gas Networks |
| UEL | Upper Explosive Limit |
| WI | Wobbe Index |
| WWU | Wales and West Utilities |

# 1 EXECUTIVE SUMMARY

## 1.1 Introduction

Gas Networks Ireland (GNI) operates both transmission and distribution gas networks in Ireland. Biomethane can be a renewable fuel, which can significantly improve the sustainability of the natural gas network and reduce dependency on imported natural gas. Biomethane is typically produced with an oxygen content above 0.2 mol% and it is not considered commercially viable to produce biomethane with an oxygen content below this value.

In 2018 GNI introduced a new upper limit of 1.0 mol% oxygen for biomethane injected into the distribution network and, to date, there have been no adverse impacts. This increased upper limit is for biomethane injected onto the distribution network only. The upper limit for the transmission network is currently 0.2 mol%.

GNI requested Penspen to develop a report assessing the impacts of an increased upper oxygen limit of 1.0 mol% for biomethane injected on to the transmission network and to consider if such an increase would constitute a material change to the Tx safety case.

While this report supports that an increase of up to 1.0 mol% would not cause any significant safety issues / material change, it should be noted that GNI's planned Code Modification for a new oxygen limit for transmission network biomethane injection will be for a lesser limit of 0.5 mol%. Technology improvements for biomethane producers upgrade equipment and processes now facilitate biomethane with an oxygen content of less than 0.5 mol%.

Section 11 of this report references Mitchelstown Central Grid Injection (CGI) facility. This CGI, is to be located in County Cork and will facilitate the injection of biomethane into the transmission network. When it is fully built, it will be able to inject up to 20,000 scm / hr of biomethane.

GNI carried out two network planning studies assessing the increase of the upper oxygen content of biomethane injected at the Mitchelstown CGI. The first is in relation to an upper limit of 1.0 mol% and the second is in relation to an upper limit of 0.5 mol%. The analysis was based on current network planning scenarios. Network analysis shows that an oxygen upper limit of 1.0 mol% would result in a worst-case oxygen level of 0.2522 mol% at a nearby plant during summer min flow days when the CGI is injecting at a rate of 20,000 scm / hr. An upper limit increase of 0.5 mol%, as per the proposed Code of Operations modification, results in a worse-case oxygen level of 0.1656 mol% at this plant, in similar circumstances, which is below the current 0.2 mol%.

In addition, GNI commissioned a separate study[1] to assess how biomethane and natural gas will mix at the Mitchelstown CGI. The results show that the gases will comingle well and there should not be slugs of biomethane in the natural gas flows.

It is important to note that the natural gas in the GNI network is a relatively dry gas. This is important as the key to maintaining acceptable corrosion rates within the pipeline systems is to limit the water / moisture content, rather than the corrosive species such as oxygen. Given that the gas in GNI's network is dry, corrosion should not be an issue in GNI's network.

Penspen / GNI reviewed the risk and agreed that the ALARP assessment would be based on a type B decision as per CRU guideline document CER/16/106 ALARP Guidance (see Section 10 of this report and GNI HSQ Safety Case Impact and Risk Assessment).

The following conclusions and recommendations are presented below:

## 1.2 Conclusions

The following conclusions were drawn from the assessment work;

- Increasing the oxygen content to 1.0 mol% will have:
  - No effect on the PE distribution network.
  - A negligible effect on the steel distribution and transmission networks (i.e. no increase on the risk category within the safety case). This is provided that the mitigation measures (monitoring and automatic diversion of off specification gas, Section 10.3) that have already been recommended are implemented.
  - No significant effect on the lower and upper explosive limits (LEL and UEL) of the gas, both for leaks and gas at pipeline pressures.
  - No significant effect on corrosion of transmission and distribution end user equipment.
- Increasing the oxygen content to 1.0 mol% will reduce the calorific value of the gas slightly (by less than 1.5%) due to the reduction in hydrocarbon content of the gas. The producer’s gas will still need to meet the calorific value specification as set out in Part G of the GNI Code of Operations (see table 3-1).
- The use of the proposed mitigation measures will demonstrate that the introduction of 1.0 mol% oxygen is ALARP (see Section 10).
- Increasing the oxygen content to 1.0 mol% is not considered to have a significant effect on operability of end user equipment, although validation and minor alterations may be necessary.
- The key to maintaining acceptable corrosion rates within the pipeline systems is to control the water / moisture content rather than the corrosive species, such as oxygen.
- An increase to the upper limit for oxygen in biomethane injected into the transmission does not constitute a material change to the safety case – see Section 10 for supporting details.

## 1.3 Recommendations

The following recommendations are made:

- This report recommends implementing a biomethane oxygen limit increase on the Transmission from 0.2 mol% up to 0.5 mol%
  - The report assessment does not identify any significant safety impacts / material change resulting from an upper oxygen increase to 1.0 mol%. Therefore, the lesser value of 0.5 mol% content mitigates any risk even further.

- Recent improvements in biogas to biomethane upgrading technology facilitates implementing an increase to 0.5 mol%, which should be achievable by biomethane producers.
- The 0.5 mol% is more aligned with current European limits (see Section 5).

- Automated valve arrangement to divert off spec gas including oxygen greater than 0.5 mol% to be installed at all RNG Tx entry points.

- Recommendations for end users are **not** strictly within the remit of this report. However, the following will assist the smoother acceptance of a higher oxygen limit;
  - Operators of gas turbine systems should consider retuning their turbine control systems if required.
  - Where required, increased oxygen content to be incorporated into their fuel quality specification.
  - Procurement of future gas turbines are specified with higher oxygen levels.

# 2 INTRODUCTION

## 2.1 Background

Gas Networks Ireland (GNI) operates both transmission and distribution gas networks in Ireland. GNI has recognised that biomethane can be a renewable fuel which can significantly improve the sustainability of the natural gas network and reduce dependency on imported natural gas. Consequently, the company is developing arrangements for the injection of biomethane into its transmission network.

Biomethane is typically produced with an oxygen content of above 0.2 mol%, and it isn't considered commercially viable to produce biomethane with an oxygen content of less than 0.2 mol%, so it is likely that some biomethane sources will not be able to meet this limit. Currently the oxygen limit for injection into the network is 0.2 mol%, apart from biomethane injected on to the distribution network, which can have an upper oxygen limit of 1.0 mol%. GNI is now assessing the impact of increasing the oxygen limit of biomethane injected on to the transmission network up to 1.0 mol%.

GNI has requested[2] an assessment to be completed that shall consider the safety and operational implications for the transmission network of biomethane injection with an upper limit for oxygen of 1.0 mol%. The report should recommend a safe oxygen limit for the transmission network. Consideration shall be given to demonstrating ALARP in line with regulator guidelines, CER/16/106 ALARP Guidance[3].

It is important to note that the gas in the GNI network is a relatively dry gas. This is important as the key to maintaining acceptable corrosion rates within the pipeline systems is to limit the water / moisture content, rather than the corrosive species such as oxygen. Given that the gas in GNI's network is dry, corrosion should not be an issue in GNI's network.

For all Biomethane Network Entry Facilities (BNEFs) on GNI's network, there is, and will be, continuous monitoring of water / moisture content and oxygen. If the biomethane gas is found to be outside of specification limits, it will automatically be diverted, preventing it from entering the GNI gas network.

GNI is currently developing a CGI facility which will facilitate the injection of biomethane into the transmission grid adjacent to the Corracunna above ground installation (AGI), near Mitchelstown, County Cork. When it is fully built, this CGI will be able to inject up to 20,000 scm / hr of biomethane.

## 2.2 Objective

The objective of this report is to determine whether a proposal to increase the oxygen content of transmission biomethane from 0.2 mol % to 1.0 mol% would be acceptable and to consider if such an increase would constitute a material change to the Tx safety case. Acceptability would be based on the principle of ALARP, in line with regulator guidelines, CER/16/106 ALARP[3].

## 2.3 Scope

This assessment will cover the transmission network. The assessment will consist of three activities, namely:

1. **Corrosion Assessment:** The effect of the proposed increased oxygen content will be studied. Principal activities will be to determine whether there would be increased corrosion if the oxygen content was increased and, if there was, would it be significant

compared to other forms of corrosion. The likelihood of any corrosion at all occurring will be evaluated, (see Section 8).

2. **Explosion Assessment**. The likelihood of the biomethane / natural gas having a greater tendency to explode will be evaluated, (see Section 7).

3. **Calorific Value**: A change in the calorific value of the biomethane / natural gas will be assessed, (see Section 6).

The likelihoods will then be assessed to determine whether their effect on pipeline integrity is within the ALARP region.

The methodology is given in more detail in Section 4. Downstream appliances have also been considered as discussed in Section 9.

# 3 ASSET DETAILS

GNI operate both transmission and distribution networks. The transmission network consists of steel pipelines with maximum allowable operating pressures in the range 19 to 85 barg. The distribution network consists mostly of polyethylene pipelines and some steel pipelines operating at maximum allowable operating pressures of 4 barg and 7 barg respectively.

The current quality specification of the natural gas was supplied[4]. The information contained within the specification that is relevant to the current work is given in Table 3-1.

| Parameter | Specification |
|---|---|
| Total Sulphur (including Hydrogen Sulphide) | <50 mg/m$^3$ |
| Oxygen | ≤0.2 mol% |
| Carbon Dioxide | ≤2.5 mol%* |
| Hydrogen Sulphide | ≤5 mg/m$^3$ |
| Water Content | ≤50 mg/m$^3$ |
| Gross Calorific Value (Real Gross Dry) | 36.9-42.3 MJ/m$^{3\#}$ |
| Wobbe Index (Real Gross Dry) | 47.2-51.41 MJ/m$^{3\#}$ |
| Delivery Temperature | 1°C to 38°C |
| Nitrogen | ≤5 mol% |

**Table 3-1 Quality specification of natural gas at entry points (excerpts)**

*GNI's Code of Operations currently provides that the $CO_2$ limit of 2.5% will not be considered breached if the total inerts (including $CO_2$) in the gas is less than 8% where: "inerts" in natural gas means carbon dioxide ($CO_2$), nitrogen ($N_2$), helium (He), argon (Ar), and oxygen($O_2$).

# These values may change due to proposed changes to gas quality specifications in the UK GS(M)R.

# 4 METHODOLOGY

The methodology for the assessment of the proposed change uses the following steps:

1. A literature review of standards and research reports covering oxygen contents and corrosion in natural gas.

2. Calculation of corrosion rates using current and proposed gas specifications.

3. An assessment of the impact of the corrosion rates resulting from the proposed gas specifications on the integrity of the pipeline networks.

4. A literature review is performed to establish the effect of raising the oxygen limit on the calorific value and explosive potential of the gas.

5. A review of the effect of injecting biomethane containing up to a maximum of 1% Oxygen at Mitchelstown.

# 5 OXYGEN LIMITS IN OTHER EUROPEAN COUNTRIES

Around Europe there are many different permitted oxygen levels in natural gas. The rationale for all the different permitted levels is not immediately apparent.

One significant factor, which has a large effect on the acceptable oxygen content, is the presence of underground storage facilities. In order to prevent bacterial growth, the permissible oxygen level for gas networks connected to underground storage is extremely low. The underground storage capacities of selected countries are shown in Table 5-1.

| Country | Capacity (TWh) |
|---|---|
| France | 132.3 |
| Germany | 260.5 |
| Ireland | 0 |
| Netherlands | 144.6 |
| Sweden | 0.1 |
| UK | 17.5 |

**Table 5-1 Underground storage capacities of selected countries[5]**

It can be seen that both Ireland and the UK have small capacities for underground storage and therefore less of a drive for low oxygen contents.

Higher oxygen content tends to be permitted in distribution grids where gas is primarily used for heating. In 2020 a survey was performed by the EU body the Agency for the Cooperation of Energy Regulators[6]. One question asked; “in which countries is biomethane currently injected into the gas transmission system?”. Seven EU countries answered in the affirmative. These were;

- Denmark
- Germany
- Italy
- Spain
- France
- Netherlands
- Sweden

## 5.1 European Standards

A European Standard, EN16726[7], was developed to standardise gas quality specifications to permit the easy transportation of gas across national borders. With respect to the permitted concentration of oxygen, the following is stated:

"At network entry points and interconnections the mole fraction of O2 shall be no more than 0.001%, expressed a moving 24 hr average. However, where the gas can be demonstrated not to flow to installations sensitive to higher levels of oxygen, e.g. underground storage systems, a higher limit of up to 1% may be applied."

The standard was approved on September 2015 and had to be adopted as a national standard by CEN members no later than June 2016. However, the standard is not legally binding for a number of reasons, principally failure to agree a Wobbe Number specification within the participating countries[8]. An ENTSOG workgroup is currently in place with view to harmonise standards across the EU. GNI is part of this workgroup.

An additional Standard EN16723 was developed to specifically cover biomethane injection into the grid and its use as a fuel. It was quickly realised that the two uses had different requirements and the standard was split into two parts; Part 1[9] covering injection into the grid and Part 2[10] coving the use of biomethane as a fuel for vehicles. The requirements of the two standards differ slightly. On one hand Part 2 permits the presence of carbon monoxide, as the fuel storage and combustion systems of a vehicle are regarded as a closed system. On the other, a number of impurities in biomethane are regarded as more problematic in vehicular fuels as they not diluted when used as fuels as they would be if injected into the grid. Regardless, the permitted oxygen content for vehicular fuels is 1%.

## 5.2 Oxygen Limits in Individual Countries

### 5.2.1 UK

In the UK the entry specification for the NTS National Grid is not more than 0.001 mol % oxygen.

The Gas Safety (Management) Regulations permit up to 0.2 mol % oxygen to be present in gas transported in the UK. However, the HSE has approved the introduction of gas containing up to 1% oxygen at pressures of up to 38 bar into the gas distribution network[11,12]. This is to permit the injection of biomethane into the gas distribution network. It is important to note that the pressure limit of 38 bar was chosen to align with existing UK pressure tiers for commercial contractual agreements and not for safety reasons.

Further details are given in Section 5.3.

### 5.2.2 Northern Ireland

Northern Ireland currently has in force a class exemption permitting the use of natural gas with an oxygen content of not more than 1 mol% at pressures up to 38 bar[13] as per proposed GS(M)R changes.

### 5.2.3 Belgium

The oxygen limits in Belgium are as follows[15];

- <0,1 mol% on the transmission grid;
- < 1 mol% on distribution grid.

### 5.2.4 Denmark

The oxygen content of Natural Gas shall not exceed 0.1 mol%[14] on a 24-hour basis for the Entry Points, the Transit Points and the Storage Points.

The oxygen content of Natural Gas/Biomethane shall not exceed 0.5 mol% for the Transition Points and the Metering Points for Biomethane.

### 5.2.5 France

The standard maximum concentration is 0.01 mol%. However, project exemptions of up to 0.7%[15] in the transmission grid and up to 0,75% in the distribution grid may be awarded if distribution centres or consumers are not affected by high levels of oxygen. The high pressure grid is at pressures of 40 bar and 70 bar[15].

### 5.2.6 Italy

The maximum oxygen concentration permitted in natural gas in Italy is 0.6 mol%[15].

### 5.2.7 Germany

In Germany natural gas containing up to a moving daily average of 0.001 mol% is permitted in high pressure pipelines (≥16 bar)[16], gas passing through borders and gas being stored in underground. For pipelines not covered above, 3% oxygen is permitted in dry gas pipelines and 0.5% in wet gas pipelines[33].

### 5.2.8 Netherlands

In the Netherlands, the maximum oxygen permitted is ≤0.0005 mol% in the high pressure main transmission network (HTL). This network operates at 40 bar to 80 bar. The regional transmission network has a maximum permitted oxygen content of ≤0.5 mol% and operates at 16 bar to 25 bar.

### 5.2.9 Spain

The oxygen limits in Spain are as follows;

< 0,3 mol% in transmission grid

< 1 mol% in distribution grid provided:

- $CO_2$ < 2mol%,
- water dew point < -8ºC, and
- biomethane flow in transmission pipelines< 5.000 $m^3$/h.

### 5.2.10 Sweden

In Sweden natural gas from biomethane containing less than 1% oxygen is permitted in pipelines[17]. Biomethane is primarily used for road transportation in Sweden.

The high-pressure network contains gas supplied by Denmark (i.e. cross border) and is connected to underground storage facilities. Therefore, the gas will be at the lower (0.001 mol%) limit in the high-pressure network.

#### 5.2.11 Switzerland and Austria

In Switzerland and Austria natural gas containing less than 0.5% oxygen is permitted in pipelines[18].

### 5.3 Comparison between Gas Networks in Ireland and the UK

A number of European countries permit significant levels of oxygen to be introduced with biomethane into at least parts of their gas networks, some of these countries are listed above. While the Irish network is more modern, the UK system most closely mirrors the Irish system both in physical terms and in legislation. There are also strong similarities between end users of the two systems, e.g. for standards for appliances, hence it is reasonable to assume no major differences between the two. Consequently, it is worthwhile to make a more detailed comparison between the gas networks of the two countries in order to determine the likely effects on the Irish system of increasing the oxygen limit, as set out in the following subsections:

#### 5.3.1 Wobbe Index

The Wobbe Index is an indicator of the interchangeability of fuel gases. The two countries have identical Wobbe Index requirements.

#### 5.3.2 Transmission Systems

The UK gas transmission system consists of a National Transmission System of steel pipelines operating at pressures between 38 barg and 85 barg. There are also Local Transmission Systems that operate at pressures above 7 barg.

The Irish gas transmission system consists of steel pipelines operating at pressures between 19 barg and 85 barg.

There is little difference between the two systems except for the lower pressure limits.

#### 5.3.3 Distribution Systems

The UK gas distribution system is divided into three pressure classes. These and the materials of construction are shown in Table 5-2:

| Pressure | Materials of Construction |
|---|---|
| 30 mbarg to 75 mbarg | Steel, PE and cast iron |
| 75 mbarg to 2 barg | Steel, PE and cast iron |
| 2 barg to 7 barg | Steel and PE |

**Table 5-2 Distribution system pressure classes in the UK**

The gas distribution system in Ireland is divided into two pressure classes. These and the materials of construction are shown in Table 5-3. Small quantities of cast iron are still present in the distribution network.

| Pressure | Materials of Construction |
|---|---|
| 30 mbarg to 4 barg | PE |
| Up to 7 barg | Steel |

**Table 5-3 Distribution system pressure classes in Ireland**

The GNI network is more recently installed than that in the UK. This would suggest that the likelihood of internal corrosion in the network would be lower. Whilst the UK network uses PE pipelines at higher pressures, there is little practical difference between the two systems.

Odorant is injected into the distribution network to aid detection of leaks in the UK. GNI inject odorant into the transmission network for the same reason. The compounds used tend to be based on sulphur and have been associated with corrosion in gas turbines which is why the UK do not inject into the transmission network.

## 5.4 Ongoing Initiatives in the UK

### 5.4.1 Proposed Changes to GS(M)R

The Health and Safety Executive (HSE), and the Department for Business, Energy and Industrial Strategy (BEIS) are working closely with the Institution of Gas Engineers and Managers (IGEM) to develop safe options for revising GSMR. This is in order to broaden the range of viable gas sources, reduce costs and open up the Regulations to facilitate any potential future changes needed to address Net Zero. A consultation process has been initiated for the proposed changes[19].

The purposes of the changes are to enable;

- The adaptation of prescriptive GB regulation for gas composition contained in GS(M)R Schedule 3 that is restricting the sources of gas sitting outside of current specifications being used in the gas transmission and distribution network;
- A greater diversity of gas resources to be accessed from biogas and across the North Sea including both the United Kingdom Continental Shelf (UKCS) and the Norwegian sector;
- Reduced gas processing, potentially making gas supplies greener and easier to secure and more economically viable;
- Regulations to be updated and modernised in order to ensure safety standards are consistently applied across today's gas network.

The changes include;

- A new lower Wobbe number (WN) limit;
- To incorporate the HSE class exemption limit of ≤1 mol% for oxygen in gases conveyed at pressures up to 38 barg;

- It should be noted that the HSE could consider an extension of the oxygen content limit at pressures beyond 38 barg to enable the use of biomethane throughout the gas network. However, the limit of 38 barg is to ensure the higher oxygen content is not conveyed in the transmission network. This is important because of interconnector agreements for export gas and the extent to which a wider oxygen content limit may reduce calorific value of export gas. The UK-EU Trade and Cooperation Agreement commits the UK to co-operate on gas markets, security of supply, infrastructure planning and gas quality. It is possible that a higher oxygen content at pressures above 38 barg could impinge upon the UK trade responsibilities and have ramifications for other territories.

- Clarity that biomethane pipelines are to be considered to be part of the gas network.

The changes must maintain, or improve, the safety standards that have been achieved to date by the Gas Safety (Management) Regulations 1996 (GSMR).

IGEM also produced a consultation document that supported many of the proposed changes including the relaxation of the oxygen specification[20].

### 5.4.2 Other Changes and Trials

Cadent Gas has made a 70 barg biomethane pipeline connection and commissioned an investigation into removing pressure limit on biomethane oxygen exemption in 2019[21].

Adapt Biogas (formerly BioCow) started injecting biomethane directly into the National Grid's high-pressure National Transmission System in 2020, the first time that this has taken place in the UK[22]. The gas quality required was not specified in the press release.

# 6 CALORIFIC VALUE

## 6.1 Calorific Value

Calorific Value is usually incorporated within the Wobbe number which is a ratio of calorific value to the square root of the Relative Density (as defined in GS(M)R). An increase to 1.0 mol% for the oxygen could have a small effect on the Wobbe by reducing the proportion of flammable gas, if the increase in oxygen was at the expense of the methane component. In this case oxygen is considered an inert gas. The reduction would be expected to be around 1.5% in the Wobbe number[23]. This reduction could normally be accommodated by the permitted range in Wobbe number.

Alternatively, if the increased oxygen level was accompanied by a reduction in the concentration of one of the other inert gases then there would not necessarily be a change in the Wobbe number.

It is possible to increase the Wobbe number of gas blended with additions of propane or an increase in the proportion of rich (e.g. LNG) gas. However, without these measures it is likely that there would be a slight fall in Wobbe number, as indicated earlier in this section.

# 7 EXPLOSION AND FLAMMABILITY ASSESSMENT

## 7.1 Effect of Concentration

Earlier work[18] has concluded that oxygen limits of up to 1% should not result in any significant risk of explosion. A minimum oxygen concentration of around 10% was regarded as the lower level at which the explosive risk could increase.

A flammability diagram for methane, oxygen and nitrogen was included in a similar reference[23]. This diagram indicated that there is a negligible change in the lower explosive limit (LEL) between an air/methane mixture containing no oxygen and one containing 1% oxygen. There was also no significant difference between these mixtures and one of pure oxygen and methane. The lower explosive limit in all these cases was approximately 4.4%[33].

In pure methane/oxygen mixtures, the upper explosive limit (UEL) increases to 60% methane but the flammability diagram also indicated that there was a negligible difference in the UEL between an air/methane mixture containing no oxygen and one containing 1% oxygen (approximately 16% methane). The above statement concerning oxygen limits of around 10% being the lower level at which the risk of explosion increase is based on gas mixtures containing this level of oxygen being capable of ignition without the presence of additional oxygen from air.

Consequently, for biomethane containing up to 1% oxygen, there is no requirement to alter the settings of gas detection equipment.

### 7.1.1 Effect of Pressure

The effect of pressure on the upper explosive limit was examined[24] to assess the risk of explosions happening at elevated pressures, i.e. within piping and equipment. The upper explosive limit of methane oxygen mixtures at various pressures were determined and are presented in Figure 7-1.

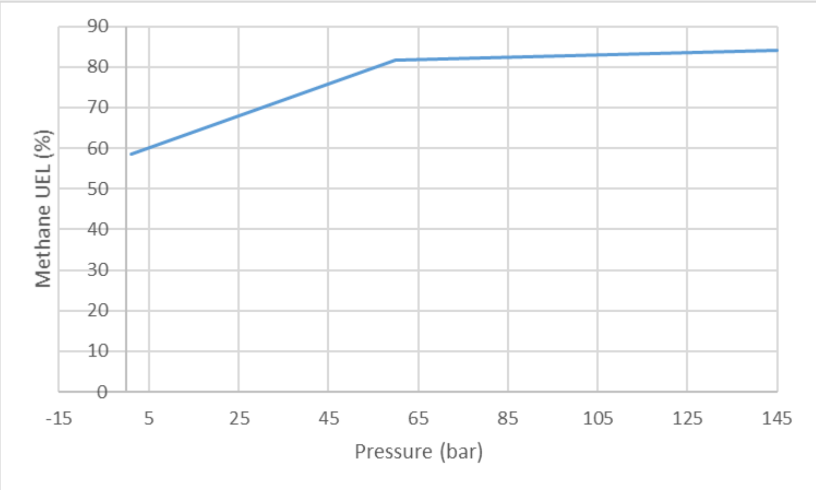



**Figure 7-1 Effect of pressure on UEL of methane oxygen mixtures**

It may be seen that the UEL increases with pressure. However, with the proposed 1 mol% oxygen, the mixture will never come close to the upper explosive limit. The presence of small percentages of other inert gases will not encourage ignition, and in large quantities will prevent it.

Therefore, there is no significant increase in risk of explosion for a 1% oxygen content under normal pipeline pressures.

# 8 CORROSION REVIEW

## 8.1 Corrosion in Natural Gas Pipelines

Corrosion in natural gas pipelines can be caused by the following corrosive species:

- Carbon dioxide;
- Hydrogen sulphide;
- Oxygen.

It is important to note that in the absence of free water there will be no corrosion.

## 8.2 Corrosion Models

### 8.2.1 Carbon Dioxide Corrosion

Carbon dioxide corrosion is the most commonly studied form of internal corrosion, especially in the oil and gas industry. Over 15 models are known to exist. Some are internal company models and some are freely available in the public domain. The other main difference between the models is that some are purely empirical, being based on observation of pressure, temperature etc. on corrosion rates in laboratory and field experiments. Others attempt to be mechanistic, starting with the chemical equations thought to be occurring and the transfer of electrons and corrosive species and trying to build models from theory, rather than from experimentation, although using the latter for validation.

Probably the best known and accepted models are those of de Waard et al of Shell. The basic equation of the model developed in 1993 [25] is shown below;

$$log(CR) = 5.8 - \frac{1710}{t + 273} + 0.67\log\left( p_{CO_2} \right)$$

Where;

CR = Corrosion rate (mm/yr)

T = Temperature (°C)

$P_{CO2}$ = Partial pressure of carbon dioxide (bara)

The basic equation can then be modified for fugacity, water cut, the actual pH of the liquid and the presence of glycol.

A weakness of the '93 model is that it does not consider the velocity of the fluid, and it is known that high velocity will increase the corrosion rate.

Further experiments were performed and the result was the De Waard et al '95 model[26]. This model took the general form;

$$\frac{1}{V_{corr}} = \frac{1}{V_r} + \frac{1}{V_m}$$

Where;

$V_{corr}$ = Corrosion rate (mm/yr)

$V_r$ = The highest possible reaction rate, i.e. mass transfer is infinitely fast. Its form is similar to the ’93 model.

$V_m$ = The highest possible mass transfer rate. The term includes the liquid velocity.

The ’95 model therefore includes the effect of liquid velocity but at low velocities can under predict corrosion rates. For stagnant and low flow conditions, the ’93 model can be more appropriate.

It is interesting to note that the NORSOK M506 corrosion model[27] was based on the same experimental data as the ’95 model but has a very different form.

Freecorp[28] is a freely available piece of software produced by Ohio University. It uses a mechanistic model and is included here as it also includes the effect of oxygen on carbon dioxide corrosion and was used both in earlier work[23] and this work.

### 8.2.2 Oxygen Corrosion

Oxygen corrosion is often not considered when assessing hydrocarbon pipelines, principally due to the supposed absence of oxygen from these pipelines. However, oxygen ingress is possible, at compressors, pumps and in storage tanks where the inert atmosphere above the liquid hydrocarbon may contain significant amounts of oxygen. In the present case involving gas, the oxygen would be admitted to the pipeline network as a component of the biomethane.

A number of rate prediction models exist for oxygen corrosion. The two best known and accepted of these models are those of Oldfield et al [29] and Andijani and Turgoose[30]. These are both intended for flowing liquids.

The primary variables considered by these two models are oxygen concentration (in ppb), fluid velocity and temperature. Although the fluid velocity is used to determine fluid mechanics factors such as the Reynolds number.

It must be stated that these models are concerned with very low levels of oxygen, e.g. 10 to 100 ppb. They are commonly used in desalination plants, and also boilers and water injection where the oxygen has been removed by deaeration. Historically, it was quickly realised that carbon steel would be quickly corroded by flowing, oxygenated (sea) water. Therefore, it was an unsuitable material and little research was performed into determining the corrosion rates.

For the present work, it is also worth mentioning that the models consider oxygen content in terms of concentration (i.e. ppm) rather than partial pressure. This is relevant due to the interest in the effect of oxygen partial pressure on corrosion expressed in other work[33].

### 8.2.3 Hydrogen Sulphide Corrosion

The significance of hydrogen sulphide corrosion is usually small unless it is present in large quantities relative to carbon dioxide, with the following relationships between the respective partial pressures applying:

- $pCO_2/pH_2S>500$ Hydrogen sulphide corrosion is ignored.

- $20 > pCO_2/pH_2S > 500$ Hydrogen sulphide corrosion will result in the formation of protective corrosion products which will generally reduce corrosion but may result in pitting of no greater than the carbon dioxide rate.

- $pCO_2/pH_2S < 20$ Hydrogen sulphide corrosion will be dominant and will be difficult to predict. Carbon dioxide predictive models are not valid.

Hydrogen sulphide corrosion results in a thin tenacious film of iron sulphide scale which tends to stifle further corrosion unless the film is disrupted. If the film is disrupted, rapid pitting corrosion can occur due to galvanic effects, as the film is noble with respect to the underlying steel. Chlorides and oxygen can disrupt the film. The concentration of hydrogen sulphide in processed natural gas is usually extremely low. This is due to the processes designed to remove carbon dioxide, which could block the gas liquefaction plant, removing other acid gases too.

#### 8.2.4 Mixed Corrosion

Little research has been performed to determine the effect of oxygen on corrosion in natural gas pipelines as, until recently, sources of natural gas were generally oxygen free.

Durr and Beavers[31] conducted experiments in which gas containing carbon dioxide and oxygen was flowed over stationary quantities of pure and saltwater to determine the effect on the corrosion rate of steel samples. The maximum pressure used was 83 barg and the maximum oxygen concentration was 1,000 ppm (0.1%). Maximum corrosion rates were found at the vapour / liquid interface and at oxygen concentrations lower than the maximum concentration.

Lyle and Schutt[32] performed experiments over several years in which gas mixtures were flowed through test solutions that were all, except one set of experiments, stagnant. The concentrations of oxygen and partial pressures of carbon dioxide and hydrogen sulphide were varied. Oxygen concentrations of up to 10,000 ppm (1%) and pressures of 35 barg were used. A model was developed which took the form;

$$CR = 8.6988 + 9.856\ x\ 10^{-3}(O_2) - 1.48x10^{-7}(O_2)^2 - 1.30865(pH) + 4.934x10^{-2}(CO_2)(H_2S) - 4.8231x10^{-5}(CO_2)(O_2) - 2.372x10^{-3}(H_2S)(O_2) - 1.113x10^{-3}(O_2)(pH)$$

Where:

CR = General corrosion rate (mpy)

O2 = Oxygen concentration of gas (ppmv)

CO2 = Carbon dioxide partial pressure (psi)

H2S = Hydrogen sulphide partial pressure (psi)

pH = Initial pH of solution.

The use of imperial units should be noted.

Freecorp[28] is a mechanistic carbon dioxide corrosion rate models which also considers the effect of oxygen and hydrogen sulphide on corrosion, although it cannot evaluate the effect of both corrosive species at the same time. The use of the model for oxygen contents above 10,000 ppb (0.001%) is not recommended and the software will not work when an oxygen content of 10,000,000 ppb (1%) is entered.

An alternative approach used in some studies[18] is to consider oxygen and carbon dioxide corrosion separately and to consider the effects of the two corrosive species as additive.

## 8.3 Previous Studies

Health and Safety Executive research report RR882[33] prepared by GL Noble Denton in 2011 reviewed a number of possible consequences of permitting the introduction of biomethane into the distribution network. The report stated that increasing the oxygen content from 0.2 % to 1 % would double the carbon dioxide corrosion rate by disrupting the scales of corrosion product. It was further stated that these values were the result of using a model that was only validated to a partial pressure of oxygen of 0.345 bar. Consequently, it was recommended that further research be performed. This work referred to the use of the model proposed by Lyle and Schutt[32].

A similar study was performed for Scotia Gas Networks (SGN)[23] by GL Industrial Services in 2009. This study used Freecorp software[28] to perform the corrosion calculations and concluded that, although the increase in oxygen from 0.2% to 1% resulted in an increase in the overall corrosion rate by five times, this did not significantly affect the integrity of the pipeline, even when considered over 100 years. The reason for this was that the majority of the time the line was assumed to be dry, and without free water there would be no corrosion.

A weakness in this study when used in relation to the present work is that it only considered a pressure of 2 barg. This is in part due to the perceived need for models valid for higher partial pressures of oxygen[18]. An additional reason to exercise caution in using these results is that at only 2 barg total pressure and with 1% oxygen present, there is proportionally much more oxygen present than when the pressure is much higher. It would be expected that at higher pressures, the effect of the carbon dioxide would be greater.

Following on from the work undertaken for the HSE a corrosion study was performed for Wales and West Utilities (WWU) by GL Nobel Denton[34]. The purpose of this work was to estimate the corrosion risk to steel pipelines from permitted oxygen concentrations of greater than 0.2%. The pressures considered by the work were between 75 mbarg and 14 barg. The Lyle and Schutt[32] model was also used for this work.

A number of issues were found with this report. These include;

- The Lyle and Schutt model assumes no movement of the liquid which was causing the corrosion.
- The work was reported to calculate corrosion rates at 38°C, the maximum inlet temperature for the UK grid. The experiments on which the model was based were performed at 60F (15.6°C) and the model itself does not contain a variable for temperature. The pH variables were adjusted for temperature but this is small compared to the effect that varying the temperature would be expected to have on a chemical reaction.
- The use of 38°C is also questionable as at this temperature no free water would be expected to be present. This is because it is far above the specified dew point.
- The work attempted to determine the effect of varying the partial pressure of oxygen. However all the corrosion rate models included in this report use oxygen concentration (ppm or %) rather than partial pressure (bara). The latter being used for carbon dioxide. If the input of a model including both oxygen concentration and carbon dioxide partial pressure was modified by increasing the total pressure then an increase in the corrosion rate would be expected. However, the most likely reason for this would be

the well-known relationship between carbon dioxide partial pressure and corrosion rate, rather than the increase in oxygen partial pressure which in not used as an input to any of the establish hed corrosion rate models described here.

The overall conclusion that the inclusion of 1% oxygen would not cause significant additional corrosion in a gas distribution system is reasonable. This is principally due to the short proportion of the time that the line is wet and therefore sees any corrosion at all. The low pressures present in the distribution network would also result in low corrosion rates during the periods when water was present.

## 8.4 Corrosion Rate Calculation

### 8.4.1 Corrosion Rate Selection

As discussed above in Section 8.2, no corrosion rate model has been found that had been validated for both 80 barg and 1% oxygen in addition to carbon dioxide corrosion. Upon reviewing the above models, the Freecorp software has been selected as one of the cases is within its stated validity. Electronic Corrosion Engineer (ECE) software[35] a commercial development based on the de Waard ’95 model was used to calculate an oxygen free carbon dioxide corrosion rate for comparison, as was a manual calculation using the de Waard et al ’93 model.

The input data for the corrosion rate calculations are given in Table 8-1. The velocity was assumed. It is much less than the 5-10 m/s expected as a gas velocity as small amounts of water tend to travel along a pipeline at a slower rate than the gas.

| Parameter | Value |
|---|---|
| Temperature | 15°C |
| Pressure | 80 barg |
| Velocity | 0.5 m/s |
| Carbon dioxide | 2.5 mol% |
| Oxygen (Case 1) | 0.2 mol% |
| Oxygen (Case 2) | 1 mol% |

**Table 8-1 Calculation inputs**

### 8.4.2 Oxygen Concentration

The two oxygen concentrations used are the existing limit of 0.2% and the proposed new limit of 1%. These are the concentrations in the gas phase. To determine the concentration in the (assumed) water, Henry’s law will be used.

$$K_H = \frac{p_{O_2}}{(O_2 aq)}$$

Where $K_H$ is the Henry’s law constant which for this case is 769.23 atm/M.

For 0.2% oxygen

$$\frac{0.002 \times 80}{769.23} = 2.08 \times 10^{-4} M/l$$

The molar weight of oxygen is 32g therefore the concentration is

$$2.08 \times 10^{-4} \times 32 = 0.006656 g/l$$

Or 6.66 ppm.

For 1% oxygen

$$\frac{0.01 \times 80}{769.23} = 0.00104 M/l$$

The molar weight of oxygen is 32g therefore the concentration is

$$0.00104 \times 32 = 0.033 g/l$$

Or 33 ppm.

### 8.4.3 Corrosion Rate

Using the data from the two sections above the rates shown in Table 8-2 were calculated. The corrosion rates are in millimetres per year. They may appear alarming but it should be noted that corrosion will only occur when free water is present and that the default state for a gas network is dry rather than wet.

| Model | Oxygen (ppm in water) | Oxygen (% in gas) | Corrosion Rate (mm/yr) |
|---|---|---|---|
| Freecorp | 0 | 0 | 2.3 |
| Freecorp | 6.6 | 0.2 | 4.1 |
| Freecorp | 33 | 1.0 | 11.5 |
| ECE | 0 | 0 | 1.21 |
| De Waard '93 | 0 | 0 | 0.96 |

**Table 8-2 Corrosion rates**

The results show that increasing the permitted oxygen content from 0.2% to 1% would increase the corrosion rate by 2.8 times. Even the current limit increases the corrosion rate compared with the oxygen free case.

The Freecorp oxygen free case is significantly higher than the ECE result. Whilst the ECE is a well established and accepted piece of software, this is not totally unexpected. 0.5 m/s is the bottom of the velocity range for which the software claims its highest level of accuracy and, as the experimental results for a velocity of 1.5 m/s were disregarded in the original work due to their being a poor fit[26], even the 0.5 m/s claim might be regarded as optimistic. Often the '93 model will give a higher corrosion rate than the '95 model at low velocities, but this has not occurred on this occasion. This appeared to be due to the low temperature.

Only the lower (0.2% in gas or 6.6 ppm in water) oxygen was fully within the validity range of the Freecorp software. The higher oxygen concentration was within the range when the software would still operate but outside the recommended range (known as the soft limit by the software). This was still regarded as more valid than the use of other models or software.

The most important point to note is that no corrosion will occur without the presence of free water. This is discussed further in Section 10.

### 8.5 Effect of Partial Pressure of Oxygen

Previous work has described the absence of experimental data on corrosion at high partial pressures of oxygen[34]. This is of moderate concern but is mitigated by the following points.

The work for WWU[34] modelled corrosion at pressures up to 14 barg and oxygen contents of up to 5%. The modelling appeared to show a levelling off of corrosion rates at the highest pressures and oxygen concentration. See Figures 5 to 9 of the reference. Figures 10 and 11 of the reference, which apparently show an increase in corrosivity, do not separate the effects of oxygen and carbon dioxide. An increase in the partial pressure of carbon dioxide increasing the corrosion rate is well known[25].

The fugacity of a real gas will reduce at high pressures in comparison to an ideal gas. This means that it will be less chemically active.

Oxygen is thought to increase sweet corrosion rates by interfering with the formation of iron carbonate scales, which can slow down corrosion. At ambient temperatures, scale formation is not so noticeable so its protective effect will be less. Therefore, damage to the scale should be less important.

### 8.6 Gas Dryness

Gas dryness will affect the corrosivity of the gas - without free water being present there will be no corrosion. Gas is normally considered dry, with respect to corrosion, if its dew point is lower than the ambient temperature minus 10 °C. GNI carries out, and will continue to carry out, regular network inspections and pig runs. These exercises confirm that free water has not been found inside the pipework and the gas in GNI's network is dry.

The main sources of gas into Ireland are given and discussed in subsequent sections.

#### 8.6.1 Interconnectors (from the UK)

The Interconnectors supply gas from the National Grid NTS. Water content measurements from the NTS are not publicly available but National Grid closely monitors gas quality at system entry points. In addition, National Grid is contractually obliged to inform GNI of any excursions. A water dew point of ≤ -10 °C at 85 barg is specified which approximates to a water content of 50 ppm. The proportion of natural gas in the UK that originates from LNG[36] has been increasing in recent years and now stands at 22%. This gas tends to have a particularly low water content as discussed in the next section.

GNI plans (PC5) to install water content analysers downstream of the Moffat entry point of the two Interconnector pipelines.

#### 8.6.2 LNG Gas

LNG typically has an extremely low water content (e.g. < 1ppm). Concerns over water freezing in the liquefaction section of the LNG result in a tight inlet specification. As water in the process could stop production, there is a strong incentive to conform to the water specification.

#### 8.6.3 Corrib Gas

Gas from the Corrib field is transported from offshore to be processed in an onshore processing facility and is then injected into the grid. The water content of the gas is continuously monitored.

#### 8.6.4 Biomethane (Proposed)

The proposed injection of biomethane at the Mitchelstown CGI will involve the use of gas trailers, from which the biomethane will be taken. The gas will be analysed for moisture at the Biomethane Producer’s facility and at the CGI injection site, to ensure no off-specification gas is injected into the network.  Any off-specification gas will automatically be diverted away from the pipeline.

# 9 IMPACT ON END USER EQUIPMENT

In principle, changing the oxygen content of natural gas or biomethane could affect the following:

- Theoretical air requirement;
- Caloric value;
- Flammability;
- Minimum ignition energy;
- Flame temperature;
- Burning velocity;
- Corrosion.

Calorific value and flammability have already been discussed in Sections 6 and 7. Changes to these parameters were not considered to have significant effects. The other factors were evaluated in a previous work[23] and are described below. The likely effects on specific types of equipment are then considered.

## 9.1 Factors

### 9.1.1 Theoretical Air Requirement

The theoretical air requirement for stoichiometric combustion will vary by an insignificant amount between an air/methane mixture containing no oxygen and one containing 1% oxygen.

### 9.1.2 Minimum Ignition Energy

Changes in the minimum ignition energy would be expected to be small for oxygen levels of up to 3%. The 1% oxygen is well within this level. Therefore, no significant effect would be expected.

### 9.1.3 Flame Temperature

For a stoichiometric methane/air mixture the flame temperature would be expected to increase from 2226 K to 2230 K which was not regarded as significant ((2230-2226)/2226=0.18%).

### 9.1.4 Burning Velocity

A stoichiometric methane/air flame has a burning velocity of 35.2 cm/s. An increase in the oxygen content from zero to 1% oxygen increases this to 35.6 cm/s. This was not considered to have a significant effect on flame stability or to increase the frequency of burner failures.

### 9.1.5 Corrosion

Increasing the oxygen content to 1.0 mol% will not have an effect on the corrosion of end user equipment as the gas is dry and there is already an ample supply of oxygen once the gas is mixed with air. The earlier referenced report on oxygen content by GL Industrial Services[2323] concluded that there would not be a significant effect on the operability of equipment, appliances and processes. This would be contingent on the dew point specification being maintained.

### 9.2 Equipment Types

The following equipment types were considered.

#### 9.2.1 Domestic and Commercial Heating and Cooking Equipment

These may be grouped into two main kinds for the purpose of this review.

Equipment that uses partly pre-mixed burners, such as cookers, will see no impact as the oxygen in the fuel gas is inconsequential compared with the far greater amount of oxygen in the air that the fuel gas is mixed with for combustion.

For totally pre-mixed burners such as pilot lights and burners for ceramic kilns, even without modification no great impact would be expected for fuel gas oxygen levels not greater than 1.0 mol%.

#### 9.2.2 Industrial Boilers

These may be grouped into two main kinds for the purpose of this review.

Package burners would not be expected to see any impact from 1.0 mol% oxygen in the fuel gas. As with domestic heating appliances the far greater amount of oxygen in the air (21%) blown into the flame results in tiny amounts of oxygen in the fuel gas inconsequential.

In recuperative and regenerative burners, the presence of up to 1.0 mol% oxygen in the fuel gas would not affect performance significantly as such burners are usually designed to operate with a slight oxygen excess through the process. The presence of oxygen in the fuel could encourage cracking of hydrocarbons in the preheated fuel gas. This is intended to ensure complete combustion of the fuel.

#### 9.2.3 Natural Gas Vehicles

No impact is predicted to occur. An oxygen limit of 1.0 mol% is the same as that permitted by EN 16723-2 for use in vehicles powered by biomethane. Additional reassurance may be gained from the successful use of gas containing up to 3.0 mol% oxygen as a fuel for vehicles, for a number of years, in Germany.

#### 9.2.4 Gas Engines

Gas engines are frequently designed to run on a variety of fuels including biomethane. Whilst concerns have been raised about the use of fuels gases containing oxygen these are generally for oxygen levels greater than 1.0 mol%. Consequently, no issues would be expected for oxygen contents not greater than this amount. It is not possible to review all engine manufacturers here but, for example 1.0 mol% oxygen is considered acceptable for Cummins gas engines[37].

#### 9.2.5 Fuel Cells

For oxygen levels less than 2.0 mol% - 3.0 mol% fuel cells can operate without issue. Therefore a 1.0 mol% limit is considered acceptable.

### 9.2.6 Gas Turbines

Gas turbines as a class of prime mover are known for the flexibility of the fuels that they are able to run on, from heavy crude to natural gas. However, once set up, they can have a relatively narrow operating window to operate at their most efficient and to avoid damage or unacceptable emissions. It should be noted that efficient running of gas turbines depends not only on their fuel, but also the manner in which they are operated. They run best when under steady loads, close to their maximum capacity for long periods of time. Attempting to match low and fluctuating loads, as can be necessary for operational reasons, can have a deleterious effect on the efficiency, emissions and costs of operation.

Gas turbines may be grouped into two main kinds for the purpose of this review.

Diffusion flame combustors: these have a robust design and no impact would be expected.

Premixed combustors: in principle, these could be impacted by changes in the auto-ignition properties of the fuel / air mixture. However, this would not be expected to be significant below 3.0 mol% oxygen in the fuel, therefore 1.0 mol% would not be considered to have an impact[23].

Smaller microturbines, which can produce up to 1 MW, are in common usage and can run on a variety of fuels including untreated bio-gas.

Modern gas turbines tend to have automatic tuning systems that can adapt to changes in fuel composition.

Operational concerns for users of gas turbines could include;

- In addition to the actual oxygen content, the rate of change of oxygen content, could prove problematic to some GTs; and
- Using fuel not conforming to the fuel specification could void the warranty on the machines.

## 9.3 End User Comments

GNI requested feedback from a number of its larger end users on the likely impact of a 1.0 mol% permitted oxygen concentration. The responses included general comments on the previous revision of this report and specific responses from OEMs.

An edited and anonymised collection of the comments is appended to this report and further summarised in the following sections;

### 9.3.1 End Users

From the end users:

- More details on oxygen limits around Europe requested;
- Consultation of the OEMs (of gas turbines) requested; and
- Confirmation of GNI gas quality, in particular water content and the rate of change of WI.

### 9.3.2 OEMs

From the OEMs:

- The proposed change of oxygen content is outside the current fuel specifications and will require engineering assessments;
- One OEM considered that the likely result of such an assessment would be a small increased risk. That damage to the gas turbine would be unlikely but that additional equipment, such as fuel gas analysers, could be required; and
- The variation, and rate of change, of CV associated with changes in the oxygen content were queried.

### 9.3.3 Responses to Comments

The following responses to the comments have been made:

- Section 5 discusses oxygen limits around Europe.
- Maintenance of the OEM warranties for GTs will be required. For machines equipped to modern standards, this should be a compliance, rather than a technical process. However, for older GTs this may be a more involved process;
- Concerns have been raised about both a reduction in calorific value and the rates of change of calorific value associated with changes in CV. A reduction in CV might be expected with the use of biomethane. However, GNI has decided not to change the Code of Operations gas quality CV specifications for biomethane injected into transmission network. The rate of change of CV that could occur at the beginning and end of any injection of biomethane could affect the running of gas turbines. The rate of change should be managed to be within the tolerable range for the gas turbines;
- GNI have reported an absence of moisture or internal corrosion issues with their gas network. This is currently supported by monitoring and control at all network entry points. Gas quality at proposed biomethane injection sites will be continually monitored and excursions of water or oxygen outside the permitted limits into the GNI network will not be allowed; and
- The proposed PC5 initiative where GNI is seeking to install a gas monitoring system that will measure moisture at the UK entry point. This is already in place at Bellanaboy and Moneynierin.

### 9.3.4 Gas Turbine Biomethane Impact Report

GNI commissioned Uniper to prepare an internal report on the likely effect of biomethane injected at the Mitchelstown CGI on the operation of gas turbines[38].

The maximum permitted oxygen content in the fuel of stations likely to receive biomethane injected at the Mitchelstown CGI, as per the specifications, is given in Table 9-1.

| Power Station | Gas Turbine | Manufacturer | Maximum Specified Oxygen Content |
|---|---|---|---|
| C | P | X | Trace |
| A | Q | Y | Trace |
| A | R | Y | None specified |
| D | S | Z | None specified |

**Table 9-1 Permitted oxygen in gas turbine fuel[1]**

Some of the major conclusions of the report were;

- Injection of biomethane into natural gas fuel would increase the variation of fuel composition;
- Some tuning of the gas turbines might be required to ensure optimum performance with all fuel compositions;
- Major issues with the use of biomethane were not anticipated, although it was considered prudent to confirm this with the manufacturers.

[1] It was unclear what the exact definition of trace was. Although it was considered to be less than 1%. It was also uncertain if the absence of a restriction on oxygen for the manufacturers Y and Z turbines was intentional or an oversight.

# 10 RISK ASSESSMENT

GNI operates under the Gas Safety Regulatory Framework and, as such, is required to ensure that the risks associated with its operations are either broadly acceptable or ALARP. Guidance on achieving risks that are ALARP are given in CER/16/106[3].

Penspen / GNI reviewed the risk and agreed that the ALARP assessment would be based on a type B decision as this involved greater uncertainty / complexity and the decision will not be made entirely by established Good Practice. Thus while any applicable Good Practice will have to be met, there will also be a need for an engineering and/or risk assessment in order to support the decision and ensure that the risk is ALARP as well as maintaining all risk reduction measures.

## 10.1 ALARP Demonstration

The proposed increase in oxygen content is predicted to increase the corrosion rate by two to three times – see Section 8. It follows that the risk of failure would be increased by an equivalent amount. However, the probabilities of failure associated with both the current and proposed oxygen specification are considered to be insignificant due to the absence of free water (that would cause corrosion) and the mitigating measures that are applied by GNI.

The Safety Case for the Transmission System[39] assigns a risk of failure using a five by five Boston square in which Low or Very Low risk (i.e. risk ≤ 4) can be accepted without further mitigation measures, although if additional mitigation measures are reasonably practicable, they should be applied. Reviewing the Safety Case indicated that for internal corrosion, a risk of 3 (Low) was assigned. As the probability of failure has not been considered to have changed by a significant amount, and the consequences are unchanged, it is concluded that this risk level would not change. See GNI HSQ Safety Case Impact Risk Assessment[40].

The IGEM guide to risk assessment of natural gas pipelines[41] considers the likelihood of internal corrosion in pipelines which carry sweet dry gas (i.e. with mitigation measures in place) as negligible. Therefore, even if the corrosion rate has increased slightly the probability of corrosion will still be so low as to be unquantifiable or insignificant.

To demonstrate ALARP it is necessary to show that all reasonably practicable risk reduction measures have been used. For the introduction of gas with an oxygen content of up to 1.0 mol%, the proposed monitoring and off-spec gas diversion system described in Section 10.3 would be such mitigation. Therefore, ALARP will have been demonstrated.

## 10.2 Unmitigated Corrosion Threat

The study used to justify the increase in oxygen to 1.0 mol% in the UK[34] simply concluded that the risk was low if dehydration was effective. Whilst it would not be possible to perform a formal quantitative risk assessment without more data than was supplied to this work, which is limited to one hazard, a general argument may be proposed.

The corrosion rates calculated in Section 8 for 1.0 mol% oxygen are high and would not be considered acceptable. However, the rates for the existing oxygen limit and even zero oxygen are also high and would not be considered acceptable if they were to be experienced by the pipeline for the whole of its design life. With the absence of oxygen giving corrosion rates of 1 to 2 mm/yr, due to the carbon dioxide present, perforation of a 10 mm thick pipeline wall would be expected in 5 to 10 years. As such, the unmitigated risk of internal corrosion, even without the oxygen would be considered high.

### 10.3 Mitigated Corrosion Threat

The principal mitigation against corrosion within natural gas pipelines is the absence of water. The GNI pipeline network has a moisture content specification of 50 mg/m$^3$. This is generally comparable with the UK dew point specification of “not more than -10 °C at 85 bar”. If the dew point is at least 10°C below the ambient temperature, then there will be no free water available to permit corrosion.

The GNI moisture content compliance figures were not available so general sources of water were reviewed. It was reported by GNI that the expected water content of the biomethane would be 17.84 mg/m$^3$ [42]. As no corrosion would be expected at any water content below 50 mg/m$^3$ , then no corrosion issue would be expected.

The water in natural gas is usually removed at the site of production. Gas dehydration on offshore platforms is relatively effective and reliable with compliance to specification of over 99% being typical[43]. Gas supplied from LNG is even more unlikely to contain water. Water could enter the gas in underground storage facilities (e.g. salt caverns) but GNI do not currently use such facilities.

With corrosion only occurring during the 1% of the time that free water would be present (see previous paragraph), even with the high corrosion rate associated with 1% oxygen, it would be expected that perforation of the nominal 10 mm pipeline wall would not occur for around 100 years. This would result in an extremely low probability of failure in the short, medium and long term.

An Impact and Risk Assessment for a biomethane development[44] supplied by GNI recommended the use of continuous monitoring for both water / moisture and oxygen content at all biomethane entry points. These monitors would be both alarmed and connected to automatic valves, which would divert off specification gas away from the grid. If these measures were included, then the already extremely low risk could be considered negligible.

This argument is consistent with a number of the oxygen concentration limits reviewed in Section 5. In these limits the permitted oxygen concentration depends on whether the presence of water is thought probable or possible. If water is not present, then limits of 1% to 3% are permitted. Where the presence of water is considered likely, e.g. in underground storage facilities, then the limit is much lower. In one proposed limit it is 0.001%.

The possibility of water gathering in dead legs in the distribution network has been raised. The probability of this occurring in the first place would be extremely low, as it would require both a gross failure of the dehydration control of the gas source, and a similar failure of the network water content monitoring system and alarms. It would also require a flow in the line to permit the ingress of off-specification gas, and this flow would be expected to sweep any water that had gathered out of the piping. Even if water ingress did occur, the expected corrosion rate would be expected to be extremely low due to the low pressure involved. This report is primarily concerned with corrosion occurring in high pressure pipelines, but past studies have calculated the very low corrosion rates expected in distribution networks[23,34]. In true isolation, the corrosive species would be expected to be consumed but if there was contact with the bulk gas, once the dew point was restored to the specified level, the water would tend to evaporate. When the water had all evaporated, the corrosion would cease. The flow in the line which permitted the water ingress would also be expected to sweep the water out, unless the flow was an isolated occurrence. For this occurrence to happen at the same time as a dew point excursion would also be improbable.

A further possible scenario for water gathering in low points of a pipeline is following hydrostatic pressure testing. In principle, correct adherence to pre-commissioning procedures would ensure the removal of all water from a pipeline but it is not inconceivable that such procedures might not be followed exactly. Again, the passage of dewpointed gas would eventually remove the water, but there would be a period when corrosion could occur.

The PE distribution network is not subject to internal corrosion and increasing the oxygen level would have no effect on the degradation of the pipelines.

### 10.4 GNI Mitigated Control Measures

Ensuring the quality (including moisture content) in the gas to be within Code of Operation specification via:

a. All control measures as per existing safety case shall prevail.

b. Inherent design of AD facility including filtration and upgrading facilities

c. Control measures in place at AD facilities to control out-of-spec gas including oxygen

d. GNI to carry out gas sampling in line with current monitoring regime for entry points. Spot sampling will be carried out to verify parameters within specification.

e. Continuous on-site monitoring and control of oxygen and moisture levels at all biomethane entry points.

f. Automated diverter valve to divert off spec gas including oxygen greater than 0.5 mol% to be installed at all RNG Tx entry points.

g. Continuous remote monitoring and alarms on GNI SCADA with call-out procedures in place.

h. Emergency NGEM procedure process due to off-spec gas.

# 11 IMPACT OF PROPOSED INJECTION OF BIOMETHANE AT MITCHELSTOWN

GNI have performed internal network analysis to determine the effect of injecting biomethane at Mitchelstown on end users at worst case 1.0 mol% oxygen.

A variety of scenarios were evaluated. Those relevant for oxygen modelling are given in Table 11-1.

| Scenario | Description | BNEF Injection Rate |
|---|---|---|
| Scenario 5 | 22/23 Average Winter Peak | 5,000 scmh |
| Scenario 6 | 22/23 Summer Min Day | 5,000 scmh |
| Scenario 7 | 24/25 Average Winter Peak | 20,000 scmh |
| Scenario 8 | 24/25 Summer Min Day | 20,000 scmh |

**Table 11-1 Scenarios for network analysis**

The results of the network are given in Table 11-2. The identities of the end users have been anonymized to preserve privacy.

| Location | Scenario 5 | Scenario 6 | Scenario 7 | Scenario 8 |
|---|---|---|---|---|
| A | 0.022% | 0.0488% | 0.114% | 0.1911% |
| B | 0% | 0% | 0% | 0% |
| C | 0.027% | 0.0508% | 0.1244% | 0.1986% |
| D | 0% | 0% | 0% | 0% |
| E | 0.0325% | 0.0691% | 0.1342% | 0.2522% |
| F | 0.0325% | 0.0691% | 0.1342% | 0.2522% |

**Table 11-2 Oxygen levels at various locations**

The maximum Oxygen concentration observed is at Location F and Location E at 0.2522%. The maximum Oxygen concentration observed at a power station was 0.1986% at Location C. This level is within the existing oxygen (0.2 mol%) concentration specification.

A follow-up GNI internal network analysis was performed to determine the effect of injecting biomethane at Mitchelstown on end users at worst case 0.5 mol% oxygen. Results of this indicated no breach (0.1656 mol%) of existing limit of 0.2 mol% at all locations.

It should be noted that GNI also commissioned a detailed flow analysis study[45] to demonstrate the effect of mixing of biomethane and natural gas at the Mitchelstown injection point. For this study Computational Fluid Dynamics (CFD) methodology was used. No slugs of biomethane in natural gas was observed in the scenarios considered, and the gas was found to comingle well.

# 12 CONCLUSIONS AND RECOMMENDATIONS

## 12.1 Conclusions

The following conclusions were drawn from the work;

- Increasing the oxygen content to 1,0 mol% will have:
  - No effect on the PE distribution network.
  - A negligible effect on the steel distribution and transmission networks (i.e. no increase on the risk category within the safety case). This is provided that the mitigation measures (monitoring and automatic diversion of off specification gas, Section 10.3) that have already been recommended are implemented.
  - No significant effect on the lower and upper explosive limits (LEL and UEL) of the gas, both for leaks and gas at pipeline pressures.
  - No significant effect on corrosion of transmission and distribution end user equipment.
- Increasing the oxygen content to 1,0 mol% will reduce the calorific value of the gas slightly (by less than 1.5%) due to the reduction in hydrocarbon content of the gas. The producer's gas will still need to meet the calorific value specification. But, if necessary, the CV may be raised by the injection of propane or LPG.
- The use of the proposed mitigation measures will demonstrate that the introduction of 1.0 mol% oxygen is ALARP, (see Section 10).
- Increasing the oxygen content to 1.0 mol% is not considered to have a significant effect on operability of end user equipment, although validation and minor alterations may be necessary.
- The key to maintaining acceptable corrosion rates within the pipeline systems is to control the water / moisture content rather than the corrosive species, such as oxygen.
- GNI carried out two internal network planning studies[46] assessing the impacts of increasing the upper oxygen content of biomethane injected at the Mitchelstown CGI. The first is in relation to an upper limit of 1.0 mol% and the second is in relation to an upper limit of 0.5%. The analysis was based on current network planning scenarios. Network analysis shows that an oxygen upper limit of 1.0 mol% would result in a worse case oxygen level of 0.2522 mol% at a nearby CHP plant during summer min flow days when the CGI is injecting at a rate of 20,000scm/hr. An upper limit increase of 0.5 mol%, as per the proposed Code of Operations modification, results in a worse-case oxygen level of 0.1656 mol% at this plant in similar circumstances.
- GNI's commissioned an internal study to assess how biomethane and natural gas will mix at the Mitchelstown CGI shows that the gases will comingle well and there will not be slugs of biomethane in the natural gas.
- An increase to the upper limit (1.0 mol%) for oxygen in biomethane injected into the transmission network does not constitute a material change to the safety case – see Section 10 for supporting details.

### 12.2 Recommendations

The following recommendations are made:

- This report recommends implementing a biomethane oxygen limit increase on the Transmission from 0.2 mol% up to 0.5 mol%
    - The report assessment does not identify any significant safety impacts / material change resulting from an upper oxygen increase to 1.0 mol%. Therefore, the lesser value of 0.5 mol% content mitigates any risk even further.
    - Recent improvements in biogas to biomethane upgrading technology facilitates implementing an increase to 0.5%, which should be achievable by biomethane producers.
    - The 0.5 mol% is more aligned with current European limits (see Section 5).
- Automated valve arrangement to divert off spec gas including oxygen greater than 0.5 mol% to be installed at all RNG Tx entry points.
- Recommendations for end users are **not** strictly within the remit of this report. However, the following would assist the smoother acceptance of a higher oxygen limit;
    - Operators of gas turbine systems should consider retuning their turbine control systems if required.
    - Where required, increased oxygen content to be incorporated into the fuel quality specification.
    - That procurement of future gas turbines are specified with higher oxygen levels.

# 13 REFERENCES


1 CFD Simulations of Biomethane Injection into Gas Network, Dynaflow Research Group, October 2021

2 Biomethane – Oxygen Content Assessment, Reference Number: 14/008-55 Lot 2

3 Commission for Energy Regulation, CER/16/106, ALARP Guidance Part of the Petroleum Safety Framework and the Gas Safety Regulatory Framework, version 3.0, 29th March 2016

4 GNI, Code of Operations, Quality Specification of Natural Gas at Entry Points

5 Gas Infrastructure Europe, Storage Map 2021 existing & planned infrastructure

6 ACER, ACER Report on NRAs Survey - Hydrogen, Biomethane, and Related Network Adaptations, 10 July 2020

7 CEN, Gas infrastructure. Quality of gas. Group H,EN16726:2015, April 2016

8 Antonio Gómez Bruque, Joint workshop ENTSOG-Energy Community, INT NC amendment for Gas Quality, Vienna 19 October 2016

9 BS EN 16723-1:2016, Natural gas and biomethane for use in transport and biomethane for injection in the natural gas network. Specifications for biomethane for injection in the natural gas network, November 2016

10 BS EN 16723-2:2017, Natural gas and biomethane for use in transport and biomethane for injection in the natural gas network. Automotive fuels specification, August 2017

11 Health and Safety Executive, Chief Executive's Report to the Board, Paper No: HSE/13/59, 26 June 2013

12 Ofgem, Future Billing Methodology, Project NGGDLGN04/1, April 2017

13 Health and Safety Executive for Northern Ireland, The Gas Safety (Management) Regulations (Northern Ireland) 1997, Certificate of Exemption No 1 of 2022

14 Energinet, Quality and Delivery Specifications, Appendix 1

15 Marcogaz and EBA, Biomethane: responsibilities for injection into natural gas grid

16 DVGW, Gas Quality, G260

17 Bright A. et al, Advantage West Midlands and WRAP, An Introduction to the Production of Biomethane Gas and Injection to the National Grid, Project Code 280-11, Prepared by the Organic Research Agency, 5th July 2011

18 IEAGHG, Smith L. et al, Corrosion and Material Selection in CCS Systems, Report 2010/03, prepared by Intetech Consultancy Ltd and E-on Engineering, April 2010

19 HSE website, CD291 - Revision of the Gas Safety (Management) Regulations 1996

20 IGEM, A Proposed New IGEM Gas Quality Standard – A Key Step on the Pathway to Net Zero Emissions, March 2020

21 Cadent Gas, Biomethane gas to grid, Customer connection guide

22 Adapt Biogas website, Press release, 19 August 2020

23 Brown, M. et al, GL Industrial Services UK Ltd, Review of Oxygen Specification for the below 7 bar Distribution Network, Report Number: 9434, October 2009, Prepared for CNG Services Ltd,

24 Coward HF and Jones GW, US Bureau of Mines, Limits of Flammability of Gases and Vapors, 1952

25 De Waard C. and Lotz U., Prediction of $CO_2$ Corrosion of Carbon Steel, paper 93069, NACE, Corrosion 93

26 De Waard C., Lotz U. and Dugstad A., Influence of Liquid Flow Velocity on $CO_2$ Corrosion: A Semi-empirical Approach, paper 95128, NACE, Corrosion 95

27 NORSOK, M506, $CO_2$ Corrosion Rate Model, Rev 2, June 2005

28 Freecorp Background and Software, Ohio University *from website*

29 Oldfield J., Swales G., and Todd S., Corrosion of metals in deaerated seawater. INCO Ltd

30 Andijani I. and Turgoose S., Prediction of oxygen induced corrosion in industrial waters, Water Science and Technology Vol 49 No 2 pp 115–120, 2004

31 Durr C. and Beavers J. Effect of Oxygen on the Internal Corrosion of Natural Gas Pipelines, paper 96612, NACE, Corrosion 96

32 Lyle F. and Schutt, $CO_2$/$H_2S$ Corrosion under Wet Gas Pipeline Conditions in the presence of Bicarbonate, Chloride and Oxygen, paper 98011 NACE Corrosion 98

33 Broomhall D., et al, Health and Safety Executive, Hazards arising from the conveyance and use of gas from Non-Conventional Sources (NCS), Research Report RR882 prepared by GL Noble Denton, 2011

34 Saithala J. and Illson T., Corrosion aspects of nonconventional gases in the natural gas pipeline Network, GL Noble Denton, Report number 12324, 30th April 2013

35 Wood Group Intetech, Electronic Corrosion Engineer, version 5.3

36 Department for Business Energy and Industrial Strategy, Supply of Liquefied Natural Gas in the UK in 2020, Special article – Energy Trends collection 25 March 2021

37 Cummins Westport Fuel quality Calculator, On-line

38 Uniper, Impact on gas turbine power generation of Biomethane addition from Mitchelstown BNEF to the Irish gas network, Draft for comment, 22nd March 2022

39 GNI, Safety Case Transmission System, Manual No: HSQE/MN/012, Rev. 1, December

40 GNI, Safety Case Impact Assessment / Risk Assessment, Increasing limit of oxygen content for Tx network for biomethane entry points, Assessment No. IA-01000 Rev 1, 10/03/2023

41 IGEM, Assessing the risks from high pressure Natural Gas pipelines, IGEM/TD/2 Edition 2 with amendments July 2015

42 Email from Emmet Cregan, GNI, 16th January 2018

43 Confidential figures from a North Sea operator

44 GNI, Impact and Risk Assessment Cush Biomethane-Issue 1, Spreadsheet dated 13th November 2017

45 CFD Simulations of Biomethane Injection into Gas Network, Dynaflow Research Group, October 2021

46 TX OP SR3452248 Mitchelstown BNEF Gas Travel Jan 2021 and TX NC (SR4213606) Mitchelstown CGI O2 Content December 2022

APPENDIX 1
quality specification of Natural Gas at IP Entry Points and Entry Points

**Appendix 1**
**QUALITY SPECIFICATION OF NATURAL GAS AT ENTRY POINTS**

| Parameter | Entry |
|---|---|
| Total Sulphur | < 50mg/m$^3$ (including $H_2S$) |
| Oxygen | ≤ 0.2 mol% * See Renewable Natural Gas Notes |
| Carbon Dioxide | ≤ 2.5 mol % See Note 1 |
| Hydrogen Sulphide | ≤ 5mg/m$^3$ |
| Water Content | ≤ 50mg/m$^3$ |
| Gross Calorific Value (Real Gross Dry) | 36.9 - 42.3 MJ/m$^3$ |
| Wobbe Index (Real Gross Dry) | 47.2 – 51.41 MJ/m$^3$ |
| Contaminants & Odour | See Notes 2 and 3 |
| Incomplete Combustion Factor | < 0.48 |
| Delivery Temperature | 1$^o$C to 38$^o$C |
| Hydrogen | < 0.1 mol% |
| Soot Index | < 0.60 |
| Organo Halides | < 1.5 mg/m$^3$ |
| Radioactivity | < 5 Becquerels/g |
| Ethane | < 12 mol% |
| Nitrogen | ≤ 5 mol % |
| Hydrocarbon Dewpoint | ≤ - 2$^o$C up to 85 barg |

**Reference Conditions**
All measurements at 15º Celsius and 101.325kPa

**Note 1** The CO2 limit of 2.5% will not be considered breached if the total inerts (including CO2) in the gas is less than 8% where:
“inerts” in natural gas means carbon dioxide (CO2), nitrogen (N2), helium (He), Argon (Ar), and oxygen(O2).

**Note 2** Natural Gas shall not contain solid liquid or gaseous material which may interfere with the integrity or operation of pipes or any Natural Gas appliance which a consumer or transporter could reasonably be expected to operate. With respect to Mist, Dust, Liquid, gas delivered shall be technically free in accordance with BS3156 11.0

[1998].

**Note 3** Natural Gas shall have no odour that might contravene the obligation of the Transporter to transmit gas which possesses a distinctive and characteristic odour. Where the Transporter requires gas to be odourised, the gas shall be odourised in accordance with the following specification:
- Odour intensity of 2 olfactory degrees on the SALES Scale (Ref-IGE/SR/16/1989), or
- such other specification determined by the Transporter acting as an RPO

**Emergency Gas Quality Specification**
In the event of an Emergency, and at the sole discretion of the National Gas Emergency Manager, gas outside of the Entry Specification may be admitted to the system. Without prejudice to the generality of this, the emergency limits as outlined in the Natural Gas Emergency Plan NGEP may be adopted by the Transporter.

**Renewable Natural Gas Notes**

1. Oxygen content for gas derived from Renewable Natural Gas at an RNG Entry Point

    (a) connected to the Distribution System shall be ≤1 mol%; and
    (b) connected to the Transmission System shall be ≤ 0.5 mol%

   in each case where there is provision for automatic discontinuation of gas flows for non-compliance with the applicable Entry Specification. Such automatic discontinuation shall comprise of the discontinuation of gas flow based on pre-programmed criteria, such criteria determined by the Transporter and embodied in an automated process, all as outlined in the applicable CSA or other applicable agreement.

2. The CSA or other applicable agreement in respect of any RNG Delivery Facility may, subject to the approval of the Commission, specify additional gas quality parameters (which may for avoidance of doubt be subsets of the parameters set out above) and associated limits in respect of such parameters to apply at the individual RNG Entry Point or category of RNG Entry Point in which case the gas quality parameters so specified shall (subject to Renewable Natural Gas Note 1 above) apply at such RNG Entry Point(s) in addition to the parameters set out above. [**Note: Refer Part G (*Technical*) Section 1.1.1**]

3. To avail of the oxygen content upper limit for Renewable Natural Gas at an RNG Entry Point on the Transmission Network the Transporter must be of the reasonable opinion that an increased oxygen content in respect of RNG delivered, or tendered for delivery, to the Transmission Network would not adversely impact the End User operational facilities (save to the extent any potential adverse impact could, in the opinion of the Transporter, be reasonably mitigated by the End User) and would not adversely affect the Transmission Network.