

Hydrogen Impacts on Downstream Installations and Appliances

COAG Energy Council *COAG Kickstart project extension - downstream installations and appliances Technical Review*

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EXECUTIVE SUMMARY

On behalf of the COAG Energy Council, the South Australian Government Department of Energy and Mining (SAG DEM) and Future Fuels Cooperative Research Centre (FFCRC) commissioned GPA to undertake a study which reviewed the safety and technical impacts of addition of up to 10% hydrogen (by vol) into natural gas on end users.

This study reviewed the impacts of up to 10% hydrogen blended in natural gas on end-users supplied from the distribution network. The study completed a desktop review, which identified the individual user types as well as the different type of appliances, and piping installations.

A review of current domestic and international research and testing was completed. The review identified, that in particular, the results of the following projects should be leveraged:

- Future Fuels Cooperative Research Centre (FFCRC) / the Australia Gas Association (AGA) / University of Adelaide (UoA) - Type A appliance testing
- Mondo Laboratory - Type A and Type B appliance and component testing
- ATCO - Type A appliance testing
- Evoenergy - Appliance and component testing

The study then reviewed the implication of addition of up to 10% hydrogen on the gas quality parameters and combustion characteristics of natural gas. The blended gas has generally comparable combustions characteristics and behaves similarly to that of unbended natural gas. For up to 10% hydrogen there is additional materials risk – notable embrittlement especially as the pressure increases, and increased leakage from permeation and through joints, fittings and components.

The study completed a technical review of the impact of up to 10% hydrogen to domestic, commercial, industrial, feedstock, compressed natural gas users and the associated piping installations. The review found the following:

- Domestic appliances (Type A) are likely suitable for up to 10% hydrogen, however, it is recommended that further investigation of the impact of hydrogen to flame stability and materials is completed.
- Commercial and industrial appliance (Type B) are likely suitable for up to 10% hydrogen, however, it is recommended that further investigation of the impact of hydrogen to the flame stability and materials is completed. For these appliances, it is expected that any additional safety risks can be managed by tuning and minor modifications to the appliance.
- Users of compressed natural gas (CNG) face an increased risk of embrittlement in high-pressure, steel storage vessels, piping and components. The risk of failure increases significantly with pressure even at low concentrations. No hydrogen should be blended to a network before confirmation that the piping, equipment and components at CNG refuelling facilities are suitable.
- Feedstock users are likely suitable for up to 10% hydrogen, however, it is recommended that further investigation of the impact of hydrogen to the efficiency and safety of the applications is required. For these applications, any additional safety and performance risks can be managed by tuning and minor modifications; however, these will be required on a case-by-case basis. Additionally, there are a limited number of feedstock users supplied by the distribution network.
- Piping installations, which connect the distribution network to the appliance, are likely suitable for up to 10% hydrogen, however, it was recommended that further detailed review of the materials found in the network are completed and assessed for suitability.

A desktop review of the standards identified as applicable to the gas appliances was completed. The following standards were reviewed:

- AS 3814:2014 – Industrial and commercial gas-fired appliances

- AS/NZS 5263.0:2016 – Gas appliances – General installations
- AS/NZS 5601.1:2013 – Gas installation – General installations
- AS/NZS 4563:2004 – Commercial catering gas equipment
- AS/NZS 1869:2012 – Hose and hose assemblies for liquefied petroleum gases (LPG), natural gas and town gas

Identified during the review of the key relevant technical standards were:

- AS 3814 found that industrial and commercial appliances is likely to be suitable for up to 10% hydrogen.
- AS/NZS 5263.0 and AS/NZS 4563 further investigation is required to understand the impact of hydrogen on the flame speed of the appliances covered in these standard.
- AS/NZS 5601.1 further investigation into the materials compatibility of these installations including further investigation of the increased safety risks of embrittlement and leakage.
- AS/NZS 1869 further investigation into the materials compatibility of these installations including further investigation of the increased safety risks of leakage.
- There are additional standards that were outside the scope of this report that should be reviewed for the impacts of up to 10% hydrogen.

On completion of the technical and safety standards review, a set of clear recommendations have been developed addressing each aspect and a suite of potential barriers identified. These recommendations, and proposed timeframes for their implementation, are outlined in further detail in section 7 of this report.

Table 1 Recommendations that have been made as part of this study

Recommendation	Details
Review additional standards and update existing standards as identified by this study.	<p>Further investigation into technical suitability of, and implications to the relevant Australian standards be completed, in particular:</p> <ul style="list-style-type: none"> • Desktop review of the technical standards that were outside the scope of this report or identified during this report. These standards include: <ul style="list-style-type: none"> ○ AS 5092:2009 – CNG Refuelling stations ○ AS/NZS 5263 - complete series¹ • Detailed further review of following standards is necessary to ensure the suitability for up to 10% hydrogen. <ul style="list-style-type: none"> ○ AS/NZS 5263.0 ○ AS/NZS 4563 ○ AS/NZS 5601.1 ○ AS/NZS 1869 • Minor updates of the following standard during the next revision cycle to remove any barriers for hydrogen injection: <ul style="list-style-type: none"> ○ AS 3814
Complete further assessment of flame stability in Type A, appliances	<p>Further investigation of the technical impacts of new and existing Type A appliances be completed, in particular, the impacts to flame stability and the consequences of increased moisture production from combustion.</p> <p>Although, it is likely that flame stability of Type A gas appliances will be suitable for up to 10%, further testing is required to provide satisfaction that this is the case.</p> <p>Note: There is currently testing in progress by AGA labs (contracted by FFCRC), University of Adelaide (UoA), Evoenergy, ATCO and Mondo Labs that can be leveraged.</p>
Complete a detailed review of type B appliances found in the distribution network.	<p>Investigation of the technical impacts to new and existing Type B appliances should be completed, in particular:</p> <ul style="list-style-type: none"> • Detailed review of the materials used in Type B appliances and suitability assessment for 10% hydrogen/natural gas blend. • Testing of Type B appliance burners to confirm that there are no increased safety impacts to flame stability. Testing of appliances with little or no tuning capabilities should be a priority.

Recommendation	Details
	<ul style="list-style-type: none"> • Detailed review and identification of appliances/processes that are temperature sensitive and analysis of the impacts to these in particular <ul style="list-style-type: none"> ○ Glassmakers ○ Brick works • Review the impacts of increased NO_x generation for Type B appliances. • Review the impacts of increase water vapour to un-flued appliances.
Complete a detailed review of feedstock users using natural gas.	A scoping study to identify all feedstock users supplied from the distribution network.
Investigation of CNG infrastructure before injection of hydrogen.	Investigation of the technical impacts of new and existing Type B appliances be completed, in particular: <ul style="list-style-type: none"> • Detailed review of the materials used in CNG infrastructure and suitability assessment for 10% hydrogen/natural gas blend, including identification of steel vessels for high-pressure steel storage (Generally high strength Type 1 and Type 2 vessels).
Complete a detailed review of materials found in end-user installations.	Investigation of the technical impacts to new and existing installation components and methods should be completed, in particular: <ul style="list-style-type: none"> • Detailed review of the materials used in installation components and suitability assessment for 10% hydrogen/natural gas blend. • Review of the impacts to safety of the construction techniques and installation quality currently used in consumer applications.

Generally, the knowledge gaps identified can be addressed by current research and projects being undertaken domestically and internationally. Industry test programs and research organisations should be leveraged, where possible, to develop further knowledge.

Areas for further work covering aspects that were not included in the scope of this report were identified as a logical progression from the work undertaken to date. In particular, consideration should be given to undertaking an economic, regulatory and commercial review of the impact of up to 10% hydrogen on natural gas appliances.

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1 INTRODUCTION

1.1 BACKGROUND

In December 2018, the Council of Australian Governments (COAG) Energy Council committed to a vision of making Australia a major player in a global hydrogen industry by 2030. As early steps to achieving this vision, the COAG Energy Council has committed to:

- Develop and implement a national strategy for hydrogen, in close consultation with industry and the community, known as the National Hydrogen Strategy (NHS), and
- Deliver the three *kickstart* projects in partnership with industry and the community.

The COAG Energy Council approved a high-level work plan and established the Hydrogen Working Group. The key milestones under the work plan included the development of a draft strategy for consideration by Ministers, followed by submission of the final strategy to COAG.

The COAG Energy Council *kickstart* project under the National Hydrogen Strategy (NHS) *Gas in the distribution network work stream*, prepared by GPA Engineering, led by the South Australian Government in conjunction with the Future Fuels CRC, issued a report on the “technical and regulatory barriers of up to 10% of hydrogen by volume blend in the natural gas distribution network”. The physical limit of this study was from the metered hydrogen injection point and metered blended offtake from gas distribution networks. The study assessed some of the likely technical impacts on end users of blending of up to 10% hydrogen by volume in the gas distribution network. The study also aimed to identify barriers in the current Australian Standards for adoption of up to 10% hydrogen by volume.

One of the **key recommendations** from this initial work was to complete a **review of the technical and regulatory impacts to end users of up to 10% hydrogen** in the natural gas distribution network **downstream of the consumer billing meter**.

1.2 OBJECTIVE

The objective of this study is to identify the technical impacts to the “end-users” of natural gas downstream of the consumer billing meter in Australian distribution networks, when up to 10% hydrogen (by volume) is homogeneously mixed with natural gas.

1.3 SCOPE

The physical limits of this study are the equipment (appliances), components and piping downstream of the consumer billing meter.

Figure 1 provides graphical representation of the scope of this report.

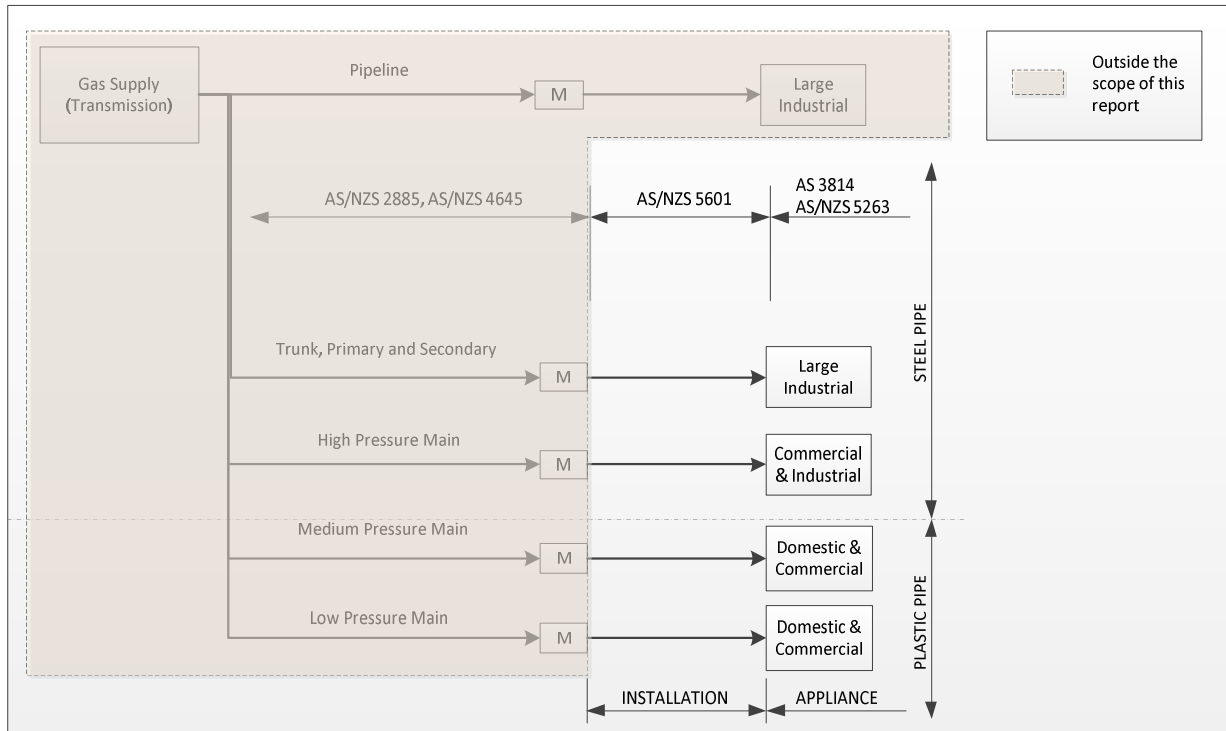


Figure 1 Scope of this report

The objectives of this study are to:

1. Identify where the use of up to 10% hydrogen in natural gas affects the end users supplied by the distribution network.
2. Identify where up to 10% hydrogen in natural gas impacts the application of relevant Australian Standards.
3. Provide recommendations to address technical uncertainty and remove the barriers identified in the technical standards and highlight where further work is required.
4. Identify areas for further investigation that were not explicitly part of the scope.

Note:

1. The study assumes a limit of 10% hydrogen (by volume) blended homogeneously in natural gas. Consideration is given to short-term excursions above a limit of 10% hydrogen (by volume), but higher concentrations of hydrogen are excluded from this study. Review of higher concentrations of hydrogen is an area for future work.
2. This work did not consider the economic, regulatory or commercial impacts of addition of hydrogen in natural gas. Review of the economic, regulatory and commercial impacts is an area of interest for further work.
3. This study excluded liquefied natural gas (LNG). Due to high demand and pressure requirements, LNG processing facilities gas supply is from the natural gas transmission network, which was outside the scope of this study. Review of the impact of hydrogen to LNG facilities may be an area for future work.
4. This study excluded reticulated LPG networks. LPG networks constitute only a minority of the overall gas networks in the Australia and are independent to natural gas networks (i.e. no connection exist between those networks).

1.4 METHODOLOGY

A series of desktop reviews were undertaken. These included:

- Types of end-user appliances, processes, equipment, and consumer installations supplied by gas from the natural gas distribution network within Australia.
- Previous outcomes of the research and test projects, both domestically and internationally for effects of up to 10% hydrogen natural gas blends on end users.
- Implications of addition of up to 10% hydrogen (by volume) including assessing gas quality, combustion, flame characteristic and stability, risk and safety, and materials.
- Technical and safety impacts to end-users, including:
 - Domestic gas-fired appliances that use natural gas for heating, cooking and hot water systems;
 - Commercial and industrial gas-fired appliances;
 - Industrial users of natural gas as a feedstock;
 - Compressed Natural Gas (CNG) infrastructure; and
 - Piping installations¹ –downstream of the *consumer billing meter* to the appliance inlet.
- Impact to key relevant technical Australian standards, which apply to the end-users included in the scope of this report.

Finally, recommendations were then made where barriers in technical standards and gaps in knowledge were identified.

1.5 ABBREVIATIONS AND DEFINITIONS

Table 2 provides a list of abbreviations applicable in this report.

Table 2 Abbreviations

Abbreviation	Description
ACT	Australian Capital Territory
AGA	Australian Gas Association
API	American Petroleum Institute
ANSI	American National Standards Institute
AS	Australian Standard
ASME	American Society of Mechanical Engineers
BMS	Burner Management System
BSP	British Standard Pipe
COAG	Coalition of Australian Government
CNG	Compressed Natural Gas
CSA	Canadian Standards Organisation
FFCRC	Future Fuels Cooperative Research Centre
GTRC	Gas Technical Regulators Committee
HDPE	High density polyethylene
HHV	Higher heating value
HNBR	Hydrogenated nitrile butadiene rubber
HTHA	High temperature hydrogen attack

¹ Piping installation is the system of pipes, fitting and components from the consumer billing meter that conveys gas to the appliance inlet.

Abbreviation	Description
LEL	Lower explosive limit
LFL	Lower flammability limit
LHV	Lower heating value
LNG	Liquefied Natural Gas
LPG	Liquid petroleum gas
MAOP	Maximum allowable operating pressure
MN	Methane number
NT	Northern Territory
NSW	New South Wales
NZS	New Zealand standard
PA	Polyamide
PE	Polyethylene
PFTE	Polytetrafluoroethylene
PVC	Polyvinyl chloride
SA	South Australia
SI	Spark ignition
SMYS	Specified minimum yield stress
SG	Specific Gravity
TAS	Tasmania
UAN	Urea ammonium nitrate
UFL	Upper flammability limit
UK	United Kingdom
VIC	Victoria
WA	Western Australia
WI	Wobbe Index

Table 3 provides a list of definitions applicable in this report.

Table 3 Definitions

Definition	Description
10% hydrogen	For the purpose of this report hydrogen the hydrogen concentration in natural gas will be considered for a maximum of up to 10% (by volume). Except where it is explicitly stated otherwise.
Appliance	An assembly, other than a vehicle refuelling appliance, part of which uses gas to produce flame, heat, light, power or specials atmosphere. ²
Burner	A device that introduces fuel and air into a heater at the desired velocities, turbulence, and concentration to establish and maintain proper ignition and combustion.
Consumer billing meter	A gas meter to record the gas used by the consumer, generally located on the edge of the property. ³ This meter falls within the scope of the distribution network and is the network owner/operator's responsibility.
Consumer Piping	A system of pipes, fitting and components (within the scope of AS/NZS 5601.1),

² AS 3814:2018 Section 1.4.4

³ (Standards Australia - AS/NZS 5601.1, 2018) Section 1.8.50.1

Definition	Description
	and equipment that conveys gas to the inlet of an appliance. ⁴
Direct fired	Arrangement whereby combustion products flow through with the heated gas stream e.g. in a direct fired air heater the heated air and combustion products are released together.
Distribution network	Gas distribution networks, with the scope of AS/NZS 4645, comprise of all facilities between the outlets of the city gates and the outlet of the consumer billing meter assembly.
Elastomer	High molar mass material which when deformed at room temperature reverts quickly to nearly original size and form when the load causing the deformation has been removed. ⁵
End-user	The final consumer of the distributed gas, typically for use as a fuel gas or as a process feedstock.
Gas exchangeability	The ability to commingle or exchange natural gases from different sources for use of this commingled mixture in various applications including industrial engines, gas turbines, gas appliances and in feedstock applications without material change in operational safety, performance and efficiency, and within an acceptable variation in the air pollution.
Higher heating value	The amount of energy (in MJ/Sm ³) released when one cubic metre of dry gas, at standard conditions, is completely burnt in air with the products of combustion brought to standard conditions, and the water produced by combustion condensed to the liquid state. ⁶
Legacy appliance	Appliances no longer manufactured but still present in households and commerce.
Liquefied natural gas	Natural gas, which has been cooled to approximately -160°C, at which temperature it becomes liquid at atmospheric pressure.
Natural gas	Produced gas, primarily methane that has been processed to remove impurities to a required standard for consumer use. It may contain small amounts of ethane, propane, carbon dioxide and inert gases such as nitrogen.
NO _x	A generic term for the nitrogen oxides that are most relevant for air pollution, namely nitric oxide and nitrogen dioxide.
Off-specification gas	Gas, which does not comply with the gas quality specifications for that system injection point.
Type A	An appliance for which a certification scheme exists (applicable in Australia only). ⁷
Type B	An appliance, with gas consumption in excess of 10 MJ/h, for which a certification scheme does not exist (applicable in Australia only). ^{8,9}
Wobbe Index	A physical parameter of gas quality. ¹⁰ It is expressed in MJ/Sm ³ and is calculated when the higher heating value of the gas is divided by the square root of the relative density of that same gas.

⁴ (Standards Australia - AS/NZS 5601.1, 2018) Section 1.8.19

⁵ (ISO 1382:1996)

⁶ (Standards Australia - AS 4564, 2011) Section 1.6.2

⁷ (Standards Australia - AS/NZS 5601.1, 2018) Section 1.8.2.1

⁸ Type A appliances, when used in an industrial/commercial application for which it was not intended are considered to a Type B appliance. An example of this is a certified direct-fired air heater used as the heating/ventilating device in a spray/bake paint booth.

⁹ (Standards Australia - AS/NZS 5601.1, 2018) Section 1.8.2.2

¹⁰ (SAE International, 1986)

2 UNDERSTANDING THE END-USER

This section identifies the current users within the natural gas distribution networks, appliances typically used and the types of consumer piping installations.

Typically, the majority of end-use is in the form of a “complete combustion” reaction, to convert to different energy forms like heat, mechanical or electrical energy.¹¹

The uses of natural gas downstream of the meter include:

- Space heating with both radiant and convective heaters;
- Water heating including boilers (for space heating systems and domestic hot water production and dedicated water heaters);
- Cooking heat using stoves (hobs) and ovens;
- Process heating including process burners of a wide range of designs for many different industrial processes, high pressure and high temperature hot water boilers, steam boilers, and steam generators;
- Power generation using gas turbines and gas engines; and
- As a process feedstock e.g. for ammonia or ethylene production.

Categorisation of gas appliances to *Type A* and *Type B* is based on the energy consumed, in Megajoules per hour (MJ/h), the application and the certification type. Categorisation of end-user type is by the gas retailers and is based on the total gas consumption of the user rather than on the consumption of individual equipment and appliances.

Table 4 provides a summary of the typical gas network operating pressures and the user types on these networks.

Table 4 Network supply pressures and users

Network Type	MAOP (kPag)	Network type	End-users
Low pressure mains	≤30	Distribution	Domestic and Commercial
Medium pressure mains	7 - 210	Distribution	Domestic and Commercial
High pressure and secondary mains	210 - 1,050	Distribution	Commercial and Industrial
Trunk and primary mains	1,050 - 6,895	Distribution	Large Industrial
Pipeline ¹²	>1,050	Transmission	Large Industrial

The physical limits of the distribution network are upstream of and including the *consumer billing meter*, which is typically located at the edge of a property. *Consumer piping* is downstream of the consumer billing meter and includes the pipework, fittings and components that are required to complete the installation between the meter and the appliance.

2.1 DOMESTIC

In Australia, gas distribution pipelines supply natural gas to 4.3 million households.¹³ Domestic appliances include cookers, space heaters, central heaters, water heaters, and leisure appliances supplied at low pressure from the natural gas network (<400 kPa).

¹¹ Note however that use of natural gas can include other “incomplete” reactions to other products such as the catalytic process used for methane gas reforming.

¹² (Transmission) pipelines are outside the scope of this study.

¹³ (Australian Energy Market Commission, 2019)

2.1.1 Appliances

Significant variations in the design of domestic gas appliances exist. Within one appliance type, there may be numerous commercially available options and even greater variations in the existing stock of *legacy appliances*.

Typically, domestic burners, such as kitchen cooktops, have no or minimal control of the gas to air ratio. They rely on burner design and installation settings to be able to perform over a wide turndown range.¹⁴

Table 5 provides a list of domestic natural gas appliances commonly installed in Australia.

Table 5 Common domestic appliances found in Australia

Appliance type	Appliance type
Atmospheric steamer	Gas pool heater
Barbecue griller	Gas space heating appliance
Boiling water unit	Indirect gas-fired ducted air heater
Chinese cooking table	Open and closed top boiling table
Decorative gas log appliance and similar appliances	Oven
Domestic gas cooking appliance	Overhead radiant tube gas heater
Domestic gas refrigerator	Portable gas generator with the capacity to consume no more than 500MJ/h
Domestic outdoor gas barbeque	Radiant gas heater for outdoor and non-residential use
Food warmer including bain-marie	Pasta cooker
Fryer	Rethermalizer
Gas air conditioner with the capacity to consume no more than 500MJ/h	Salamander, griller and toaster
Gas-fired water heater for hot water supply or central heating	Solid grill plate and griddle
Gas laundry dryer	Stockpot and bratt pan

Safety, performance and operation of domestic gas appliances fall under *AS/NZS 3645:2017 – Essential requirements for gas equipment*.¹⁵ This standard outlines a method for compliance for appliances that are mass-produced. Appliance manufacturers are required to test appliances in a certified laboratory to the method outlined in *AS/NZS 5263.0:2017 – Gas Appliances – Part 0: General Requirements*.¹⁶

Gas appliances that are not tested to AS/NZS 5263.0 include natural gas BBQ's and some commercial catering equipment. The compliance of these appliances is covered under AS/NZ 3645.

The Gas Technical Regulators Committee (GTRC) National Certification Database provides a list of gas appliances and components that are or have been previously certified by the five-certification bodies that are recognised individually by the GTRC members.¹⁷

Table 6 provides a list of components found in domestic appliances. Not all appliances include each component, but this table is a guide for later technical assessments.

¹⁴ (Energy Pipelines Cooperative Research Centre, 2017)

¹⁵ (Standards Australia - AS 3645:2017, 2017)

¹⁶ (Standards Australia - AS/NZS 5363.0, 2017)

¹⁷ (Energy Safe Victoria, 2019)

Table 6 Components and function found in domestic appliances

Component	Function
Burner	<p>Point of combustion. Controls safe and efficient combustion and flame stability. Generally, the air/gas ratio control in domestic appliances is fixed.</p> <p><u>Premixed</u> In a premix burner, the air and gas are mixed at some point upstream from the burner ports by a mixer. The burner nozzle serves only as a flame holder, maintaining the flame in the desired location. These burners are either forced-draught or atmospheric.</p> <p><u>Non-premixed</u> A large percentage of all domestic gas appliances employ non-premixed atmospheric burners. In an atmospheric non-premixed gas burner, the momentum of the gas jet exiting the burner injector entrains the primary air required for combustion from the surrounding atmosphere.</p>
Igniter	Ignites gas/air mixture at burner.
Pilot light	Flame to support main burner operation.
Gas valve	Gas shut-off and throttling.
Heat exchanger Flame shield Internal panel	Transfers heat from combustion zone to provide usable heat output.
Sump	Collects condensate from heat exchanger.
Flue	Controls release of combustion products to external environment. Materials of construction include aluminium, bricks, copper, fibre cement, flue bricks, mild steel, concrete, PVC-U.
Flame sensor	Safety device used to sense and regulate gas fuel released to the burner.
Automatic and manual controls	Automatic regulation of appliance heat output.
Pipework/manifold	Distributes fuel gas in appliance.
Frame (casing)	Protects components and provides casing which could allow unburnt gases to accumulate.
Oxygen depletion system (ODS)	A system which causes the gas supply to be shut off when the oxygen content falls.

2.1.2 Piping installations

Installation of domestic natural gas infrastructure from the “consumer billing meter” to “appliance” (but not including the appliance) falls under *AS/NZS 5601.1:2013 – Gas Installations – General Installations*.¹⁸ Installations are carried out by certified gas installers and, in most states, are regulated.

Table 7 provides a summary of commonly found piping, components and fittings in domestic installations.

¹⁸ (Standards Australia - AS/NZS 5601.1, 2018)

Table 7 Summary of components and fittings in domestic installations

Component/ Fitting	Type/model	Operating Pressure (kPa)	Typical materials of construction
Components			
Regulator	Various	<210	<u>Body:</u> <ul style="list-style-type: none"> • Steel • Cast Iron <u>Seals and O-rings:</u> <ul style="list-style-type: none"> • FMK (Viton N) • Nitrile Rubber (NBR, Buna N) • Polytetrafluoroethylene (PTFE)
Manual shut-off valve	Various	<210	<u>Body:</u> <ul style="list-style-type: none"> • Steel • Brass • Cast Iron <u>Seals and O-rings:</u> <ul style="list-style-type: none"> • FMK (Viton N) • Nitrile Rubber (NBR, Buna N) • Polytetrafluoroethylene (PTFE)
Consumer billing meter ¹⁹	Various	<210	<u>Body:</u> <ul style="list-style-type: none"> • Steel • Stainless Steel • Cast Iron <u>Seals and O-rings:</u> <ul style="list-style-type: none"> • FMK (Viton N) • Nitrile Rubber (NBR, Buna N) • Polytetrafluoroethylene (PTFE)
Joints			
Welded	Butt welded (ASME B16.9)	>7 but ≤ 200	Steels listed in AS/NZS 5601.1:2013 Table 4.1.
	Socket welded (ASME B16.11)	>7 but ≤ 200	Steels listed in AS/NZS 5601.1:2013 Table 4.1.
Flanged	ASME B16.9 (Class 150) AS 2129 (Class 150)	>7 but ≤ 200	Carbon Steel Steel Alloy Cast Iron
	Brazing Flange (AS 2129)	<200	Copper alloy
	Composite loose ring socket flange (AS 3688, ASME 16.5, AS1432, AS 2129)	<200	Copper alloy
Threaded	AS 3688	<200	Stainless Steel (Grade 316)
	BSP	<100	Stainless Steel (Grade 316)

¹⁹ The *consumer billing meter*, covered under AS/NZS 4645 (gas distribution network), was considered as part of this study.

Component/ Fitting	Type/model	Operating Pressure (kPa)	Typical materials of construction
Screwed	-	<7	Malleable Cast Iron
	AS 3688	>7 but ≤ 200	Copper alloy
	EN 10241 / BS 3799	>7 but ≤ 200	Wrought steel
Capillary Joints	AS 3688	<200	Stainless Steel (Grade 316)
	AS 3688	<200	Copper Alloy
Compression Fittings	Press-fit AS 3688	<200	Stainless Steel (HNBR O-rings) Copper (HNBR O-rings) Copper alloy (HNBR O-rings)
	Flared Fitting (AS 3688)	<200	Copper
	Mechanical Compression (AS/NZS 2537.5)	<70	Polyethylene
Solvent Cement	PN 12 or PN18 (AS/NZS 1477)	<70	PVC-H1 (Solvent Cement) PVC-U (Solvent Cement)
Piping			
Pipe	-	<210	All piping materials listed in AS/NZS 5601.1:2013 Table 4.1.
Hose	-	<210	All materials listed in AS/NZS 1869

2.2 COMMERCIAL AND INDUSTRIAL

Commercial and industrial customers of natural gas are from a range of industries. These customers can have fluctuating demand and a variety of applications for natural gas.

The commercial and industrial end-users reviewed as part of this study included:

- Gas appliances - for space heating, electricity generation, heat and steam, and
- Feedstock users – those who use natural gas as a feedstock for a process.

Table 8 provides a list of the industries using natural gas identified in Australia but is not exhaustive.

Table 8 Commercial and industrials users of natural gas²⁰

Industry	Application	Equipment/ Appliance
Electricity	To generate energy for electricity networks as base load generation or as a peaking plant. Additionally, industrial and commercial facilities use on-site power generation where there is a large demand or back up is required.	<ul style="list-style-type: none"> • Gas turbine • Microturbine • Gas engine • Steam turbine • Boiler
Mining	For heat in many applications in the mining industry. The mining industry also uses natural gas for on-site power generation.	<ul style="list-style-type: none"> • Gas turbine • Gas engine • Boiler • Heater
Iron and Steel	Natural gas is used for heat and steam generation in the iron and steel industry.	<ul style="list-style-type: none"> • Furnace • Heater • Boiler • Oven
Non-ferrous metals	Heat and steam are primarily used in the non-ferrous metals industries which include: <ul style="list-style-type: none"> • Alumina smelting • Copper • Nickel • Titanium 	<ul style="list-style-type: none"> • Rotary Kiln • Calciner • Boiler • Furnace • Gas engines • Heater
Non-metallic mineral products	Heat and steam are primarily used in the non-metallic mineral industry including <ul style="list-style-type: none"> • Cement • Bricks and ceramics • Glass • Magnesite 	<ul style="list-style-type: none"> • Calciner • Rotary Kiln • Boiler • Heaters • Boilers • Gas Engines • Furnace
Chemical	The chemical industry uses natural gas as a process fluid and for heat. In Australia, the chemical industry is dominated by ammonia production.	<ul style="list-style-type: none"> • Reformer • Heaters • Furnace • Boiler • Compressor
Food and beverages	The food and beverage industry use natural gas for heat and steam. The following industry groups use natural gas: <ul style="list-style-type: none"> • Bakery • Meat processing • Dairy • Beverages 	<ul style="list-style-type: none"> • Steam boiler • Oven • Hot water heater • Blood dryer • Odour burner • Gas engine • Gas turbine

²⁰ Summarised from (Smith & Panek, 2019)

Industry	Application	Equipment/ Appliance
	<ul style="list-style-type: none"> • Sugar • Flour and grain 	<ul style="list-style-type: none"> • Microturbine
Pulp and paper	The pulp and paper industry utilise natural gas for steam generation, calcination of lime and drying	<ul style="list-style-type: none"> • Boilers • Kiln • Heaters • Dryer • Oven
Petroleum refining	Petroleum refining can use natural gas in the process as a feedstock. Additionally, natural gas is used for process heat.	<ul style="list-style-type: none"> • Boiler • Heater • Distillation column • Steam cracker • Process afterburner • Steam methane reformer
Commercial and services	Commercial services primarily use natural gas for heat. Examples of these include: <ul style="list-style-type: none"> • Hospitals • Restaurants • Commercial office spaces • Accommodation • Commercial pool heating • Crematoria 	<ul style="list-style-type: none"> • Hot water boiler • Steam boiler • Commercial pool heater • Radiant heater • Continuous flow heater • Storage heater • Chiller • Oven • Hob • Stove • Kiln • Incinerator • Cremator
Transport	There are small applications of Compressed Natural Gas (CNG) in the transport industry.	<ul style="list-style-type: none"> • CNG Compressor • CNG Engine (Mobile and stationary) • CNG Storage (Mobile and stationary)
Natural gas network	The transport of natural gas through pipelines requires use of natural gas for gas fired compression equipment, cooling, valve actuation and electricity generation.	<ul style="list-style-type: none"> • Water bath heaters • Compressors • Engines • Thermoelectric generators
Special atmosphere generator	Natural gas is used in greenhouses for gas-powered generators to run UV lights, pumps, with gas fired equipment exhaust used to provide heated, moist CO ₂ rich atmospheres within the greenhouse.	<ul style="list-style-type: none"> • Furnace

2.2.1 Appliances

Like domestic users, commercial and industrial users have a wide array of appliance types. Table 9 lists the appliances supplied with gas from the natural gas network.

Table 9 Commercial and industrial appliances on the natural gas distribution network

Appliance	Description	Configurations
Stationary Turbine	<p>Gas turbines that are attached to the gas distribution network are used in a variety of applications and locations.</p> <p>Gas turbines are found coupled with an electrical generator for power generation for constant or back-up power generation or possibly as a gas compressor to provide compression.</p> <p>General-purpose steam turbines are horizontal or vertical turbines used to drive equipment that is usually of relatively small power, or is in non-critical service. They are generally used where steam conditions will not exceed a pressure of 4.8 MPa and a temperature of 400°C or where speed will not exceed 6,000 r/min.</p>	<p><u>Drive:</u></p> <ul style="list-style-type: none"> • Gas-fired • Steam • Cogeneration <p><u>Type:</u></p> <ul style="list-style-type: none"> • Aero derivative • Industrial • Microturbine <p><u>Cycle type:</u></p> <ul style="list-style-type: none"> • Open • Combined • Closed
Stationary Engine	<p>The low cost of natural gas relative to diesel and gasoline combined with various emissions related regulatory measures continues to create significant interest in natural gas as an alternative fuel for internal combustion engines.</p> <p>Engines are used to drive addition components such as a compressor, generator or a gearbox.</p>	<p><u>Mixture preparation:</u></p> <ul style="list-style-type: none"> • Premixed • Non-premixed <p><u>Injection type:</u></p> <ul style="list-style-type: none"> • Spark Ignition (SI) • Diesel pilot <p><u>Engine cycle:</u></p> <ul style="list-style-type: none"> • Otto • Diesel
Flare	<p>A flare is a critical mechanical component of a complete system design intended for the safe, reliable and efficient discharge and combustion of hydrocarbons from pressure-relieving and vapour-depressurizing systems.</p>	<p><u>Type:</u></p> <ul style="list-style-type: none"> • Endothermic • Utility • Enclosed • Single point • Multi burner • Steam-assisted, single point burner • Steam-assisted, multi-burner • Air-assisted, single-point burner • Air-assisted, multi-burner flare <p><u>Burner arrangements</u></p> <ul style="list-style-type: none"> • Up-fired • Wall-fired
Oven	<p>An industrial oven is a heated chamber that is used for a range of different heat treatment processes. They operate at extremely high temperatures and can be used for both small and large volume applications.</p> <p>A kiln is a thermally insulated chamber, a type of oven that produces temperatures sufficient to complete a process, such as hardening, drying, or chemical changes.</p>	<p><u>Types:</u></p> <ul style="list-style-type: none"> • Rotary kiln • Retort kiln • Dryer <p><u>Firing type:</u></p> <ul style="list-style-type: none"> • Indirect • Direct <p><u>Configuration:</u></p>

Appliance	Description	Configurations
		<ul style="list-style-type: none"> • Batch • Continuous
Compressors	<p>Compressors are used in natural gas transmission systems to help transport the gas from one location to another.</p> <p>Additionally, compression of natural gas is required to produce compressed natural gas (CNG).</p>	<p><u>Types:</u></p> <ul style="list-style-type: none"> • Axial • Single shaft • Centrifugal • Expander • Reciprocating
Boiler	<p>Boilers are used to provide hot water, steam or air for heating.</p> <p>A steam boiler is a vessel in which steam is generated at a pressure above atmospheric by the application of heat from the combustion of natural gas to the vessel.</p>	<p><u>Types:</u></p> <ul style="list-style-type: none"> • Steam • Hot water
Furnace	<p>Industrial furnaces are used globally for a wide range of applications. Furnaces can use natural gas to produce high temperatures.</p> <p>A calciner is a steel cylinder that rotates inside a heated furnace and performs indirect high-temperature processing (550–1150°C) within a controlled atmosphere.</p> <p>Industries, such as ammonia, methanol production, and industrial gas companies operate large steam reformers. The furnace provides the heat for the steam reforming reaction by burning a fuel and air mixture. It operates at a slight negative pressure at temperatures in excess of 1000°C with radiant heat transfer. The design of a steam reformer distributes heat as optimally as possible across the steam reformer and collects the combusted gas in a way that allows an even flow of hot gas through the furnace.</p>	<p><u>Type:</u></p> <ul style="list-style-type: none"> • Blast • Rotary • Puddling • Bessemer • Oxygen • Vacuum • Calciner • Special atmosphere generator • Incinerator • Reformer furnace <p>The steam reformer consists of two main sections:</p> <ul style="list-style-type: none"> • Furnace (also called radiant section); <ul style="list-style-type: none"> ○ Steel casing ○ Heat resistant insulation ○ Combustion air system ○ Burners ○ Flue collection system ○ Reformer tubes • Convection section. <p><u>Burner arrangements</u></p> <ul style="list-style-type: none"> • Up-fired • Down-fired • Wall-fired <p><u>Burner type:</u></p> <ul style="list-style-type: none"> • Natural draught • Forced draught
Cooker	<p>A cooker is a burner that provides direct heat for cooking.</p>	<p><u>Burner type:</u></p> <ul style="list-style-type: none"> • Premixed • Non-premixed

Appliance	Description	Configurations
		<ul style="list-style-type: none"> • Natural draught • Forced draught <u>Burner arrangements</u> <ul style="list-style-type: none"> • Up-fired • Wall-fired <u>Ignition:</u> <ul style="list-style-type: none"> • Electric • Pilot
Heater	<p>In a fired heater, heat liberated by the combustion of fuels is transferred to fluids contained in tubular coils within an internally insulated enclosure.</p> <p>The type of heater is normally described by the structural configuration, radiant-tube coil configuration, and burner arrangement.</p>	<u>Heat transfer type:</u> <ul style="list-style-type: none"> • Radiant • Convection <u>Structural configurations:</u> <ul style="list-style-type: none"> • Cylindrical • Box • Cabin • Multi-cell box <u>Radiant-tube coil configurations</u> <ul style="list-style-type: none"> • Vertical • Horizontal • Helical • Arbor <u>Burner arrangements</u> <ul style="list-style-type: none"> • Up-fired • Down-fired • Wall-fired

This list is not exhaustive but provides a cross section of the appliances in operation.

While each Type B appliance is “one-off”, they operate on the same fundamental principles for combustion. Table 10 provides a summary of the components that are applicable to Type B appliances.

Table 10 Major components in large gas-fired appliances and their function

Component	Function	Configurations
Combustion system		
Main Burner(s)	<p>Allows for the introduction of fuel and air into a heater at the desired velocity, turbulence, and air/gas ration to establish and maintain ignition and stable combustion.</p> <p>The type of burner is normally described by the emissions requirements, the method of air supply, and the fuel(s) being fired. For example, a low NO_x, natural draft (atmospheric), gas fired burner.</p>	<ul style="list-style-type: none"> • Atmospheric • Automatic • Forced draught • Induced draught • Multi-fuel alternative • Multi-fuel burner • Multi-fuel simultaneous • Part automatic burner
Injector	<p>A nozzle through which a stream of gas flows, causing air to be entrained and mixed with the gas. In an aerated burner the entrained air/gas stream is discharged through an orifice into the mixing tube or throat of the burner where secondary air is entrained prior to combustion. .</p>	
Igniter	<p>Used to light a pilot or main burner. It is dependent of the size of the burner.</p>	

Component	Function	Configurations
Mixing blower	Motor driven and on the suction side of the burner. This supplies the burner with the air and gas and generally has no control or safety features.	
Pilot	Provides ignition energy to light the main burner.	<ul style="list-style-type: none"> • Intermittent • Interrupted
Valve train assembly		
Valve train	The valve train is a combination of valves, regulators, pipe pieces and unions, immediately upstream of the burner, which form an integrated system for flow or pressure control and safe operation of the burner.	Depending on the consumption of the burner the configuration and equipment of the valve train will vary.
Isolating valve	Required to be in close proximity to the appliance and conform to AS 4617.	<ul style="list-style-type: none"> • Type 1
Safety shut off valve	Are used to shut off gas to an appliance when a signal is generated indicating the approach of an unsafe condition. Must comply with AS 4629. AS 3814 requires that the maximum leakage between the safety shut off valves be 0.05% of the maximum gas rate through the system.	<ul style="list-style-type: none"> • Class 1 • Class 2 • Class 3
Regulator	Used to control flow and/or pressure to the burner (or group of burners).	
Pipework	The piping, tubing and connections that join and seal key equipment.	
Gas filter	A gas filter is installed within the valve train to remove contaminants from the gas stream.	
Valve train enclosure	For some appliances, the valve train is within an enclosure. These enclosures are required to be ventilated and meet the requirements of AS/NZS 60079.	
Safety systems		
Flame sensor	A device that is sensitive to flame properties and initiates a signal when flame is detected.	<ul style="list-style-type: none"> • Ultraviolet • Infrared
High gas pressure device	A sensing device that is actuated when the gas pressure rises above a pre-set value.	
Low gas pressure device	A sensing device that is actuated when the gas pressure falls below a pre-set value.	
Flame safeguard system	A system consisting of the flame detectors, associated circuitry, integral components, valve, and interlocks whose function is to shut off the fuel supply to the burner(s) in the event of ignition failure or flame failure.	<ul style="list-style-type: none"> • Thermoelectric (AS 4620) • Electronic (AS 4625)
Valve leak detection unit	Used where shut-off valve requirements are met using valve proving.	
Control system		
Burner management system (BMS)	Field devices, final control elements and the logic system, dedicated to combustion safety and operator assistance in the starting, running and stopping of fuel burning equipment and for the prevention of incorrect operation of, or damage to, the fuel	

Component	Function	Configurations
	equipment.	
Damper	The adjustable device for controlling airflow in an appliance.	
Air/gas ratio control	Could be via a programmable BMS (see above), mechanical linkage between air/gas control valves, or gas proportioning regulator using combustion air reference.	
Appliance housing and components		
Heat exchanger Flame shield Internal panel	Transfers heat from combustion zone to provide usable heat output.	
Sump	Collects condensate.	
Flue	Flues are designed to discharge combustion products.	<ul style="list-style-type: none"> • Balance • Common • Natural Draught • Open • Power • Primary • Secondary • Flueless

2.2.2 Feedstock

Feedstock users employ natural gas as feedstock for a process rather than in direct combustion. Table 11 summarises the equipment that uses natural gas as a feedstock.

Table 11 Feedstock equipment

Type	Process	Typical Equipment/ Appliances	Gas network connection
Ammonia production	<p>Ammonia plant first converts natural gas into gaseous hydrogen. The method for producing hydrogen from hydrocarbons is steam reforming. The hydrogen is then mixed with nitrogen to produce ammonia via the Haber-Bosch process. Because of relatively low single pass conversion rates (typically less than 20%), a large recycle stream is required.</p> <p>The steam reforming, shift conversion, carbon dioxide removal and methanation steps each operate at absolute pressures of about 2.5-3.5 MPa, and the ammonia synthesis loop operates at absolute pressures ranging from 6-18 MPa. Ammonia is employed as a feedstock for other products including.</p> <ul style="list-style-type: none"> • Ammonium Nitrate • Urea • Nitric acid • NPK Fertilizer • UAN Fertilizer 	<p>Steam reformer Compressor Heat exchanger</p>	Transmission /Distribution
Ethylene	Ethylene is produced by the steam cracking of	Steam reformer	Transmission

Type	Process	Typical Equipment/ Appliances	Gas network connection
(Ethene)	<p>hydrocarbon fractions produced by the distillation of petroleum or natural gas.</p> <p>Ethylene is used as a feedstock for the following products:</p> <ul style="list-style-type: none"> • Polymers • Polyethylene • Epoxyethane • Ethanol • Glycol (Antifreeze) <p>In Australia, Ethylene is produced from natural gas feedstock at two sites:</p> <ul style="list-style-type: none"> • Qenos (Altona) • Orica (Botany) 	<p>Boiler Heater Catalytic cracker reactor</p>	
Methanol	<p>There are two methods for methanol production:</p> <ul style="list-style-type: none"> • High-pressure • Low-pressure <p>Each process uses pressurized synthesis gas (syn-gas) produced by the steam reforming or catalytic partial oxidation of natural gas. The syngas is a mixture of:</p> <ul style="list-style-type: none"> • Carbon monoxide • Carbon dioxide • Hydrogen <p>In the high-pressure process, the reaction of the components occurs at pressures of about 30 MPa.</p> <p>In the low-pressure process, the reaction, catalysed with a highly selective copper-based compound, operates at pressures from 5-10 MPa.</p> <p>The Coogee Methanol plant (Laverton) is the only methanol production plant in Australia. Due to the gas price exceeding \$10 per GJ (AUD), the facility has not produced methanol since 2016. This facility is supplied gas from the high-pressure transmission gas network.</p>	<p>Steam reformer Compressor Heat exchanger Turbine</p>	Transmission
Sodium cyanide (Solution)	<p>The sodium cyanide process:</p> <ul style="list-style-type: none"> • Natural gas, ammonia and oxygen are fed into reaction vessels where the mixture contacts several layers of gauzes which operate between 1,000-1,100°C. • This reaction process produces hydrogen cyanide gas. • The hydrogen cyanide is cooled before leaving the reactor. • The hydrogen cyanide gas reacts with caustic soda solution (sodium 	<p>Steam boiler Reactor furnace Boiler Compressor Absorber column</p>	Transmission

Type	Process	Typical Equipment/ Appliances	Gas network connection
	<p>hydroxide) as the gas stream passes through an absorber column, resulting in the production of sodium cyanide solution.</p> <p>There are three sodium cyanide facilities in Australia:</p> <ul style="list-style-type: none"> • Australian gold reagents (WA) • Ticor chemical company (Gladstone) • Orica (Yarwun) <p>All these facilities are supplied via the high-pressure transmission network.</p>		
Petroleum refining	<p>Liquid Petroleum Gas (LPG) is stripped from raw natural gas during natural gas processing. LPG is produced by separation during natural gas processing using an LPG gas refrigeration manufacturing process called the NGL fractionation process.</p> <p>LPG can be used as is or separated into its three primary components: propane, butane and isobutane.</p> <p>There are currently four facilities in Australia producing LPG:</p> <ul style="list-style-type: none"> • Mobil (Altona) • Viva (Geelong) • BP (Kwinana) • Caltex (Lytton) <p>These facilities are supplied from the transmission network due to the volumes of feedstock required.</p> <p>The petroleum refineries also use hydrogen for hydrocracking of petroleum fractions. In most cases, the hydrogen is produced by the steam reforming of natural gas.</p>	Compressor Heat exchanger Turbo-expanders Distillation column	Transmission

The results from the desktop review of feedstock users found that, generally, these users are supplied by high-pressure transmission network due to their large gas demand.

The impacts of addition of up to 10% hydrogen to these feedstock users are outlined later in this study.

2.2.3 Piping installations

Commercial and industrial installations can vary significantly in pressure, design elements and consumption requirements depending on the type of appliances and facility.

For the natural gas distribution network, installations are required to comply with AS/NZS 5601.1.

For commercial and industrial users with supply pressures up to and including 200 kPa, the installations and requirements for compliance are like those for domestic appliances. These should also comply with AS/NZS 5601.1.

Some installations use flexible hoses or connections in the valve train. Generally, these are in accordance with AS/NZS 1869 – Hose and hose assemblies for liquefied petroleum gas, natural gas and town gas.²¹

Table 12 provides a summary of typical installations for commercial and industrial users with supply pressures over 200 kPa. Each of these installations require individual testing and certification and compliance is performance-based rather than prescriptive. These installations generally comply with AS 4041:2016 – *Pressure piping*²² and AS/NZS 5601.1 section two.

Table 12 Summary of components and fittings in commercial applications over 200 kPa

	Operating Pressure (MPa)	Typical materials of construction
Components and Equipment (valves, meters, regulators etc.)	Operating pressure range dependant on the end-user requirement	Component materials are selected based on their suitability for service conditions.
Joints		
Welded	Operating pressure range dependant on the end-user requirement	Materials listed in AS 4041:2006
Threaded		Materials listed in AS 4041:2006
Flanged		Materials listed in AS 4041:2006
Flared, Flareless and Compression		Materials listed in AS 4041:2006
Caulked		Materials listed in AS 4041:2006
Soldered		Materials listed in AS 4041:2006
Brazed		Materials listed in AS 4041:2006
Expansion		Materials listed in AS 4041:2006
Proprietary and Special		Materials listed in AS 4041:2006
Piping		
Metallic	Operating pressure range dependant on the end-user requirement	Piping materials listed in AS 4041:2006 Appendix D. For natural gas service above 200 kPa the materials generally found in use are: <ul style="list-style-type: none"> • Carbon Steel • Stainless Steel • Polyethylene
Non-metallic	Operating pressure range dependant on the end-user requirement.	Piping materials listed in ISO 14692 and ASME B31.3

²¹ (Standards Australia - AS/NZS 1869, 2012)

²² ASME B31.3 is a direct substitution for AS 4041 in Australia

2.3 COMPRESSED NATURAL GAS (CNG)

The following section provides an overview of the compressed natural gas (CNG) infrastructure, vehicles and equipment that are currently in operation in Australia.

Compressed natural gas (CNG) is defined in *AS/NZS 5601.1:2013 – Gas Installations – General Installations* as

*“Natural gas stored under **pressure** in a cylinder”*

CNG vehicles have been promoted for some time in Australia. In 2000, their uptake was encouraged through government schemes and applied to commercial vehicles e.g. buses. As a result, there are over 3,000 vehicles fuelled by CNG currently in operation throughout Australia.

CNG requires two major components of infrastructure:

- Refuelling and storage facility, and
- A vehicle or equipment to combust the gas.

2.3.1 Refuelling and storage

Refuelling infrastructure that exists in most states receives gas from the natural gas distribution network. This is due to the network proximity to vehicle depots.

2.3.1.1 APPLICABLE STANDARDS AND REGULATIONS

The design, construction and operating of CNG refuelling stations falls under *AS 5092-2009: CNG refuelling stations*.²³

In Western Australia (WA), this standard is enforced in regulation under the Gas Safety Act.

2.3.1.2 CONFIGURATION

Natural gas is compressed to approximately 20 MPa for storage in in CNG storage vessels. The CNG is then decanted from the stationary storage vessels through a dispenser to fill vehicle “on-board” storage tanks. On the vehicle a regulator reduces the pressure of the stored gas down to a pressure that allows it to be combusted in an internal combustion natural gas engine. Figure 2 is a typical CNG refilling block diagram.

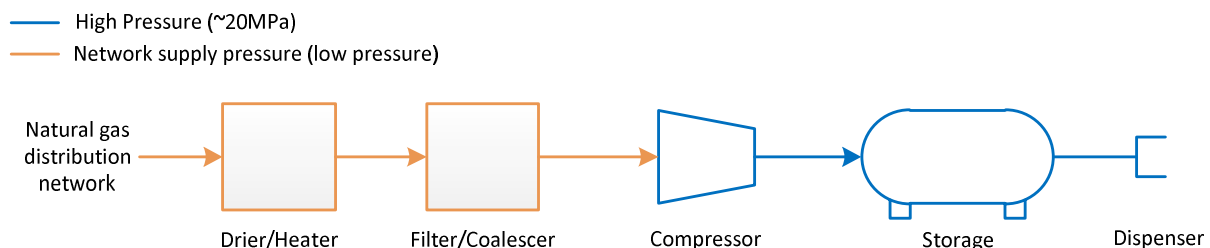


Figure 2 Compressed natural gas storage general process

²³ (Standards Australia AS 5092-2009, 2009)

Table 13 provides a summary of the processes required to produce CNG.

Table 13 Summary of CNG facility major equipment

Stage	Details	Pressure range (kPag)	Applicable Standard
Drier/Heater	The moisture from the natural gas is removed to ensure no damage to the downstream equipment.	Network supply pressure	Not Identified
Filter/Coalescer	A filter removes solids and a coalescer removes liquid contaminants from the natural gas to ensure no damage to the downstream equipment.	Network supply pressure	AS 1210 ²⁴
Compression	Gas from the distribution network can be compressed to 20 MPa.	Up to 20,000	AS 3814 ²⁵
Storage	CNG is stored at high pressures for when there is demand. Common storage type: <ul style="list-style-type: none"> • Type 1 (Steel Cylinders) • Type 2 (Steel Lined Cylinder) • Carbon Steel Pressure Vessel • Stainless Steel Pressure Vessel 	Up to 20,000	ISO 11439 CSA B51 Part 2 ANSI/IAN NGV 2 ECE R110 AS 1210
Dispenser	CNG direct from the compression or buffer storage (depending on configuration) is transferred to the on-board vehicle refuelling by a specialised CNG refueller.	Up to 20,000	ISO 14469 (Refuelling connector)
Facility Piping	Gas inlet train is designed to consumer piping standards (AS/NZS 5601.1), while the discharge piping is pressure piping (AS 4041).	0 – 20,000	AS 5601 (Gas inlet train) AS 4041 (Discharge piping)
Workshop	The workshop / building where CNG vehicles are serviced.	N/A	AS 2746

²⁴ (Standards Australia - AS 1210, 2010)

²⁵ If the compressor is gas-fired.

2.3.1.3 SITES

Table 14 provides an overview of identified CNG refuelling sites across Australia. Note, this table is not exhaustive but gives an indication of the CNG infrastructure that is currently operational in Australia.

Table 14 Example CNG refuelling sites in Australia ^{26 27}

Operator	Location	Type	Gas network type	Access type	On-site cylinder storage type
ActewAGL	Fyshwick, ACT, 2609	Refuelling	Distribution	Public	Type 1
Action buses	Greenway, ACT	Refuelling	Distribution	Private	No information available
Tas Gas	Selfs Point Road, New Town, TAS, 7008	Refuelling	Distribution	Public	No information available
Advanced fuel technology	No information available	No information available	No information available	Public	No information available
SA Gov	Adelaide (SA)	Refuelling	Distribution	Private (SA Bus fleet)	No information available
Intelligas	No information available	No information available	No information available	Public	No information available
NGV Group	No information available	No information available	No information available	Public	No information available
EDL Energy	Yulara, NT	Cylinder filling	Transmission (Palm Valley-Alice Springs natural gas pipeline)	Private	No information available
Caltex/AGL	Tullamarine, VIC	Refuelling	No information available	No information available	No information available
7-Eleven	Moorebank, NSW	Refuelling	No information available	Public	No information available

2.3.2 Vehicles and equipment

As CNG has a higher energy density than natural gas, it becomes increasingly feasible to use it as a fuel for transport and in remote applications.

2.3.2.1 APPLICABLE STANDARDS AND REGULATIONS

Design and operation of natural gas fuel systems for vehicles is covered under *AS/NZS 2739:2009 – Natural gas (NG) fuel systems for vehicle engines*.²⁸

AS/NZS 2739 must be adhered to under the following legislation:

- Dangerous Goods (Gas Installations) Regulation 1998 (NSW)

²⁶ (Gas Energy Australia, 2019)

²⁷ (Chapman, 2019)

²⁸ (Standards Australia - AS/NZS 2739:2009, 2009)

- Gas Act 2000 (TAS)
- Gas (Safety Regulations) 2014 (TAS)
- Occupational licensing Act 2000 (TAS)
- Gas and Electricity (Consumer Safety) Regulation 2018 (NSW)
- Gas Standards (Gas fitting and Consumer Gas Installations) Regulations 1999 (WA)
- Gas Supply (Consumer Safety) Regulation 2012 (NSW)
- Gas Supply (Consumer Safety) Regulation 2004 (NSW)
- Occupational Licensing (Gas-fitting Work) Regulation 2010 (TAS)
- Petroleum and Gas (Royalty) Regulation 2004 (QLD)
- Road Traffic (Light Vehicle Standards) Rules 2013 (SA)
- Road Traffic (Vehicle Standards) Rules 1999 (SA)
- Road Traffic (Vehicle Standards) Variation Rules 2009 (SA)

2.3.2.2 CONFIGURATION

For vehicle applications, the CNG is stored on-board at a high pressure (nominally 20MPag) in a fuel container. This is regulated down to the required engine supply pressure (nominally 200 kPag) then combusted in a reciprocating gas engine. Figure 3 provides a CNG vehicle system diagram.

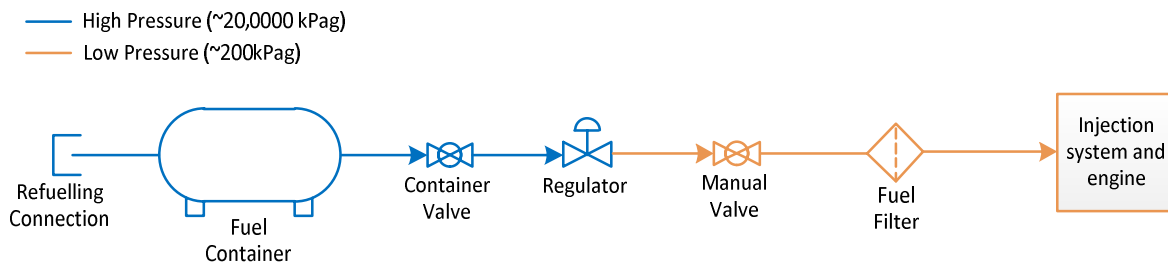


Figure 3 Typical CNG vehicle diagram of components

Table 15 provides a summary of the components that are found in a typical CNG vehicle.

Table 15 Summary of CNG vehicles components

Stage	Details	Pressure range (kPag)	Applicable standard
Refuelling connection	Required to couple to the dispenser and accept the CNG.	Up to 20,000	ISO 14469 ANSI/CSA NGV1
Fuel container (Vehicle on-board storage)	CNG is stored at high pressure using on-board storage. Common storage type: <ul style="list-style-type: none"> • Type 3 (Metal lined cylinder) • Type 4 (Composite cylinder) 	Up to 20,000	ISO 11439 CSA B51 Part 2 ANSI/IAN NGV 2 ECE R110
Container valve	Located immediately downstream of the fuel container (storage). Used to isolate the container if required.	Up to 20,000	AS 2473 ISO 15500-5 ANSI/AGA NGV 3.1
Pressure regulator	The regulator reduces the pressure from the CNG storage vessel to that required for supplying the engine.	~200 – 20,000	ISO 155000-9
Manual valve	Located downstream of the pressure regulator. Used to isolate the fuel supply for maintenance or emergency.	~200	Not identified
Piping	Piping and components capable of withstanding the pressures upstream	Up to 20,000	>100 kPa

Stage	Details	Pressure range (kPag)	Applicable standard
	of the regulator are required follow the identified applicable standards. For low-pressure, AS/NZS 1869 should be followed.		ASTM A269 ISO 15500-16 ISO 15500-20 ECE R110 <100 kPa AS/NZS 1869
Fuel Filter	Downstream of the regulator to remove contaminants from the system.	~200	Not identified
Engine	CNG is regulated to a supply pressure of 200 kPag for combustion in a reciprocating engine.	~200	AS 3814 ²⁹

2.3.2.3 VEHICLES AND EQUIPMENT

CNG is used in a variety of transport applications but commonly is found in buses, forklifts and heavy vehicles.

In addition to transport, CNG is used in stationary engines such as compressors, gas turbines and gas engines. Such applications are becoming increasingly feasible for remote sites that do not have any existing natural gas supply infrastructure.

²⁹ For stationary application

2.4 SUMMARY

Table 16 provides a summary of the end-users of natural gas in Australia.

Table 16 End-users of natural gas

	Summary
Domestic	<p><u>Summary</u> Domestic appliances include cookers, space heaters, central heaters, water heaters, and leisure appliances supplied from the low-pressure natural gas network (<400 kPa).</p> <p><u>Appliances</u> Typically, domestic burners, such as kitchen cooktops, have no or minimal control of the fuel to air ratio. Domestic appliances or “Type A” are mass-produced and compliance is achieved through a certification scheme.</p> <p><u>Piping installations</u> Includes the system of pipes, fittings and components from the outlet of the consumer billing meter to the inlet of the appliance. This can consist of pipes, valves, fittings, regulators, joints and seals. Domestic installations must comply with AS/NZS 5601.1.</p>
Commercial and Industrial	<p><u>Summary</u> Commercial and industrial customers using natural gas are from a range of industries. These customers have varying gas demand and a variety of applications for natural gas use.</p> <p><u>Appliances/Equipment</u> Like domestic users, commercial and industrial users have a wide array of appliance types. These appliances generally consume large amounts of gas.</p> <p><u>Feedstock</u> Feedstock users employ natural gas as a feedstock for a process rather than in direct combustion. There are limited feedstock users connected to the natural gas distribution network in Australia.</p> <p><u>Piping installations</u> Includes the system of pipes, fittings and components from the outlet of the consumer billing meter to the inlet of the appliance. This can consist of pipes, valves, fittings, regulators, joints and seals. Commercial and industrial installations can vary significantly in pressure, design elements and consumption requirements depending on the types of appliance and facility. For installations under 200 kPa, the prescribed requirements are like those for domestic appliances. For installations that operate over 200 kPa, the installations are “engineered solutions” where there is significant variation between facilities.</p>
CNG	<p><u>Summary</u> Compressed natural gas or CNG is natural gas that has been compressed to a high pressure (typically 20 MPa) to be used in stationary and mobile applications.</p> <p><u>Refuelling and storage</u> Natural gas from the gas network is compressed to approximately 20 MPa and stored at high-pressure in CNG storage vessels</p> <p><u>Vehicles and equipment</u> The CNG is used to fill vehicle “on-board” storage where the pressure is reduced through regulators and then combusted in a gas engine.</p>

3 RESEARCH AND PROJECTS

There are projects underway that are researching or practically testing the impacts of hydrogen on equipment and components.

Table 17 provides a summary of the relevant appliance research and testing projects domestically and internationally. These are outlined in more detail in Appendix 1.

Table 17 Summary of recent appliance testing projects

Project	Proponent	Project Type	Status
Type A appliance testing	Future Fuels CRC / The Australian Gas Association / University of Adelaide (Aus)	Appliance testing – domestic appliances	Underway (Results due end of 2019)
Type B appliance scoping study	Future Fuels CRC (Aus)	Scoping study and technical review – commercial and industrial appliances	Underway (Results due end of 2019)
Hydrogen production facility	Evoenergy (Aus)	Installation and appliance testing – domestic appliances	Underway (Preliminary results due end of 2019)
HyDeploy	Northern Gas Networks (UK)	Installation and appliance testing – domestic appliances	Underway (Phase 1 completed 2019)
Hy4Heat	Department for business, energy & industrial strategy (UK)	Research study – industrial appliances	Underway (Preliminary results late 2019)
Domestic appliance testing	ATCO (Aus)	Appliance and equipment testing – domestic appliances	Underway (Preliminary early 2020)
Domestic appliance testing	Mondo Labs (Aus)	Appliance and equipment testing – domestic appliances	Underway (Preliminary results late 2019)

The practical results from these projects should be leveraged to support the theoretical research that has been already completed, and further inform future work.

Numerous international test programmes are currently underway, examining the suitability of new and existing gas appliances. Existing appliances with increased supply pressures have been successfully tested in Europe to 28% hydrogen in natural gas. Results from international appliance testing are informative but may not be applied directly to appliances in every state due to the different appliance natural gas supply pressures.

It is interesting to note that Tasmania is already supply NG at 3 kPa which could be increased if required.

4 TECHNICAL IMPLICATIONS OF 10% HYDROGEN

The COAG Energy Council Kick Start Project *Hydrogen in the Gas Distribution Networks – Technical and Regulatory Review* identified the technical implications for blending up to 10% hydrogen into the natural gas distribution networks.³⁰

The technical implications of blending 10% hydrogen to natural gas are summarised in the following sections.

4.1 GAS QUALITY

The following gas quality parameters have both technical and commercial implications for blends of up to 10% hydrogen in 90% natural gas.

Appendix 2 presents a calculation of the gas quality parameters for 10% hydrogen in typical natural gas compositions found in each state across Australia.

AS 4564 – General purpose natural gas Table 3.1 provides the current gas quality requirements for natural gas in Australia. A review of this standard was completed as part of the first COAG Energy Council Kick Start Project.

4.1.1 Wobbe index

The Wobbe Index (WI), sometimes called the exchangeability factor,³¹ has both an upper and lower limit for appliances, within which limits appliances have been designed and tested to operate safely.

Addition of 10% hydrogen to a typical natural gas blend “reduces” the WI by approximately 2%, although this is dependent on the original natural gas composition.³² Whilst this change is minor, for a lean natural gas, such as coal seam gas, that is already near (or at) the lower limit of the WI, this could be problematic for flame stability.

4.1.2 Relative density

Specific gravity (SG), otherwise known as relative density, is the ratio of the density of a gas mixture compared with air density at standard conditions. This is an important commercial parameter in gas flow measurement and gas transactions.³³

The SG of 10% hydrogen in natural gas is reduced by approximately 10% over that of unblended natural gas.³⁴

4.1.3 Methane number

The Methane Number (MN) is a parameter used to describe the “knock” characteristics of the fuel in internal combustion engines.³⁵

Table 18 gives the MN for hydrogen and methane blends.

³⁰ (GPA Engineering, 2019)

³¹ “Gas exchangeability” is defined in the definitions and abbreviations section of this report.

³² Appendix 2 – Gas Composition Calculation

³³ (Marshall, 1941)

³⁴ Appendix 2 - Gas Composition Calculation

³⁵ (Malenshek, 2009)

Table 18 Methane number of hydrogen / methane blend³⁶

Gas composition	Methane number
100% H ₂	0
10% H ₂ / 90% CH ₄	90
100% CH ₄	100

The MN for 10% hydrogen in natural gas will be approximately 10% lower than that of unblended natural gas. Additionally, the MN reduces for a richer blend of natural gas due to the presence of heavier hydrocarbons and increases the likelihood of engine knock.

4.2 COMBUSTION

The following section reviews the impacts of 10% hydrogen on the combustion parameters of natural gas.

4.2.1 Stoichiometric composition

It is essential to determine the right air to fuel ratio during combustion. If the mixture is too lean due the excess air input or too rich due to insufficient air, it affects completeness and efficiency of combustion, flame length, temperature, shape and emissions and can result in combustion, which produces a large volume of flue gas and increased emissions.

Table 19 provides a summary of the changes to stoichiometric composition of pure hydrogen, a hydrogen/methane blend and pure methane.

Table 19 Stoichiometric compositions in air³⁷

Gas composition	Vol %
100% H ₂	29.5
10% H ₂ / 90% CH ₄	10.19
100% CH ₄	9.5

A 10% hydrogen to methane blend with air/gas ratio unchanged will cause the mixture to be leaner. For most appliances, this change will result in a small reduction in appliance performance, which in most cases will not be noticeable. However, if the appliance has a high sensitivity or low tolerance to changing air/gas ratio then appliance retuning will be required.³⁸

4.2.2 Heat of combustion

The volumetric higher heating value (HHV) represents the energy content in a volume of gas when completely burnt in air at standard conditions.³⁹

The volumetric HHV for a gas composition is the sum of the individual components' weighted percentage of the component heating values. Methane has a volumetric HHV of 37.7MJ/Sm³ while hydrogen is 12.1 MJ/Sm³ at standard conditions.⁴⁰

In appliances, the lower heating value (LHV) or heat of combustion is an input used to calculate the Wobbe

³⁶ (Altfeld, 2018)

³⁷ (Ma & Zhang, 2014)

³⁸ Tuning may not be possible in all gas appliances

³⁹ (EPCRC, 2017)

⁴⁰ (EPCRC, 2017)

Index. Table 20 gives the volumetric HHV and LHV of a 10% hydrogen / 90% methane blend.

Table 20 Volumetric HHV for 10% hydrogen / 90% methane blend⁴¹

Component	Volumetric HHV (MJ/Sm ³)	Volumetric LHV (MJ/Sm ³)
100% H ₂	12.1	10.1
10% H ₂ / 90% CH ₄	35.1	30.3
100% CH ₄	37.7	32.6

For typical natural gas compositions found in Australia the calculated reduction in HHV and LHV would be approximately 6% to 8%.⁴²

4.2.3 Moisture

When natural gas is combusted, water vapour is produced. Table 21 provides a summary from Appendix 2 of the water produced during combustion for hydrogen / methane blends.

Table 21 H₂O formed during combustion

Gas composition	Kg H ₂ O/kg of fuel
100% H ₂	9.3
10% H ₂ / 90% CH ₄	2.54
100% CH ₄	2.47

Addition of 10% hydrogen to the methane will increase the amount of water produced during combustion by approximately 3%. For natural gas, this number will be similar.

4.2.4 Yellow tipping

Yellow tipping is the generation of soot particles within a flame that radiates incandescently, exhibiting a yellow colour. If severe, this condition can result in soot deposition on downstream surfaces and can ultimately cause flue gas passages to be restricted or blocked.

For addition of up to 10% hydrogen, from the existing testing in progress it appears likely that the flame behaviour will be close to that of natural gas.

4.2.5 Emissions

4.2.5.1 NITROGEN OXIDE

Nitrogen Oxides (NO_x) are formed in high-temperature combustion due to nitrogen in the entrained air being oxidised in the combustion process. NO_x is a known environmental pollutant and greenhouse gas, and studies have found that it can have an adverse impact on health for both short and long-term exposure.⁴³

The presence of NO_x in combustion exhausts is increased by a fuel-rich combustion and increased combustion temperature.⁴⁴ Hydrogen has a higher stoichiometric combustion (complete combustion) temperature than natural gas and although many burners are operated below stoichiometric conditions, it is possible that a hydrogen burner may run hotter than a natural gas burner if the air/gas mix has not

⁴¹ Adapted from (EPCRC, 2017)

⁴² Appendix 2 - Gas Composition Calculation

⁴³ (Nitrogen dioxide in the United Kingdom, air quality expert group for DEFRA)

⁴⁴ (Jones, Taylor, & Francis, 1989)

been adjusted; this could cause material oxidation and degradation as well as higher levels of NO_x emissions.⁴⁵

The expected level of NO_x for up to 10% hydrogen in the natural gas blend is likely to be similar for the natural gas if the entrained air has been increased to prevent light back, as the additional air will reduce flame temperature.

Testing on a laminar jet diffusion flame showed that for up to 10% hydrogen there will be a NO_x increase of approximately 10%.⁴⁶ Such increase in NO_x could lead to non-compliance with existing allowable emissions limits.

4.2.5.2 CARBON DIOXIDE AND CARBON MONOXIDE

The addition of hydrogen to the gas blend reduces the volume of hydrocarbons that contain carbon. This means a decrease in carbon burnt during the combustion process that will reduce carbon dioxide (CO₂) produced, however, carbon monoxide (CO) will slightly increase.⁴⁷

The NO_x, CO₂ and CO production will also vary depending on the burner design and operating conditions.

4.3 FLAME CHARACTERISTICS

The follow section outlines the implications to flame characteristics of 10% hydrogen.

4.3.1 Flame temperature

When a combustion reaction takes place, energy is released to the combustion products. Assuming no heat is lost in this process, the temperature of the combustion productions is the “adiabatic flame temperature”.⁴⁸

Table 22 gives the flame temperature for pure hydrogen, a hydrogen/methane and pure methane.

Table 22 Published flame temperature data of gas blends in air⁴⁹

Gas composition	Temperature (°C)
100% H ₂	2045
10% H ₂ / 90% CH ₄	1880
100% CH ₄	1875

The increase in flame temperature for 10% hydrogen is less than 1% in applications such as heating. This increase may be acceptable in many applications and may improve efficiency.

For process applications that require precise temperature control, the change in flame temperature should be considered, although the increase of less than 1% is not likely to significantly affect most processes.

Additionally, an increase in flame temperature can lead to an increase in NO_x.

4.3.2 Laminar flame speed

The laminar flame speed is the speed at which a flame will propagate through a quiescent, homogeneous

⁴⁵ (Smith & Panek, 2019)

⁴⁶ (Wu, 2015)

⁴⁷ (International Energy Agency, 2003)

⁴⁸ (Bernard & Guenther, 1987) Table 1

⁴⁹ (Bernard & Guenther, 1987) Table 1

mixture of unburned reactants, under adiabatic conditions.⁵⁰

The recorded laminar flame speed for pure hydrogen and pure methane varies in the literature, as it is dependent on the test method and conditions. Table 23 provides a summary of some reported values for laminar flame speed as well as a calculated value for a method for a hydrogen/methane blend.

Table 23 laminar flame speed of gas blends

Gas composition	Report laminar flame speed (m/s)	Huang Calculated (m/s) ^[51]
100% H ₂	2.65 – 3.25 ⁵²	2.25
10% H ₂ / 90% CH ₄	-	0.58
100% CH ₄	0.37 - 0.45 ⁵³	0.39

This laminar flame speed for 10% hydrogen increases by approximately 10% over that of pure methane. In gas appliances, the value of the flame speed has important impacts on the propensity of a flame to light back and flame lift, and controls other key combustion characteristics such as the flame's spatial distribution.⁵⁴

4.3.3 Thermal radiation

Heat transfer via thermal radiation is an important mode of heat transfer in gas appliances such as furnaces.

Processes that require radiated heated will likely see a slightly drop in performance, dependent on the appliance type and burner design.

4.3.4 Flame length

For the same burner the 10% hydrogen blend will produce a slightly shorter flame length compared with a natural gas flame. Figure 4 shows a laminar jet diffusion flame at varying concentrations of hydrogen and methane.

Research completed by Wu et al. suggests that for 10% hydrogen in 90% methane the flame length will reduce by approximately 10% but is dependent on the burner design and type.

The reduction in flame length for up to 10% hydrogen is likely to have no significant impact on appliances.

⁵⁰ (Turns, 2012)

⁵¹ (Huang & Zhang, 2006)

⁵² (Bernard & Guenther, 1987)

⁵³ (Zabetakis, 1965)

⁵⁴ (Chen & Qulan, 2010)

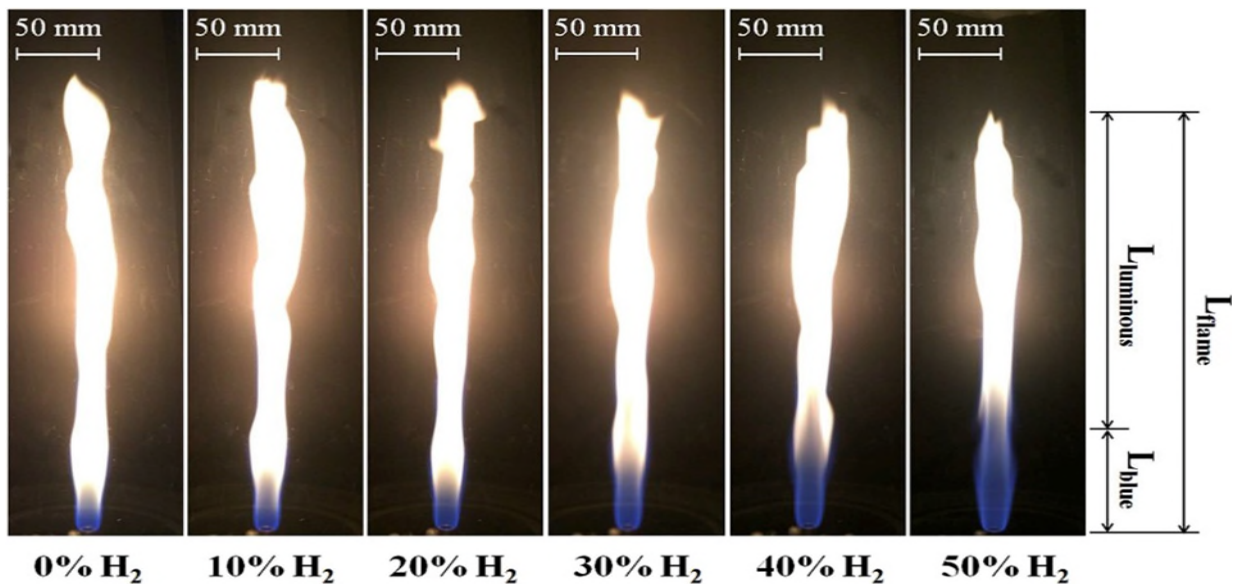


Figure 4 Flame photographs under various concentrations of hydrogen in natural gas⁵⁵

4.3.5 Flame colour

A visible flame is critical for safety in gas appliances and the addition of hydrogen affects the emissivity of the flame. Natural gas burns with a blue flame under complete combustion whilst pure hydrogen typically burns with a pale blue flame that is difficult to see in daylight conditions. Figure 5, taken from a report studying gas appliances in the Netherlands, illustrates the increasing flame speed, reduction in flame length and change in flame colour for 0% hydrogen, 10% hydrogen and 20% (from right to left).⁵⁶

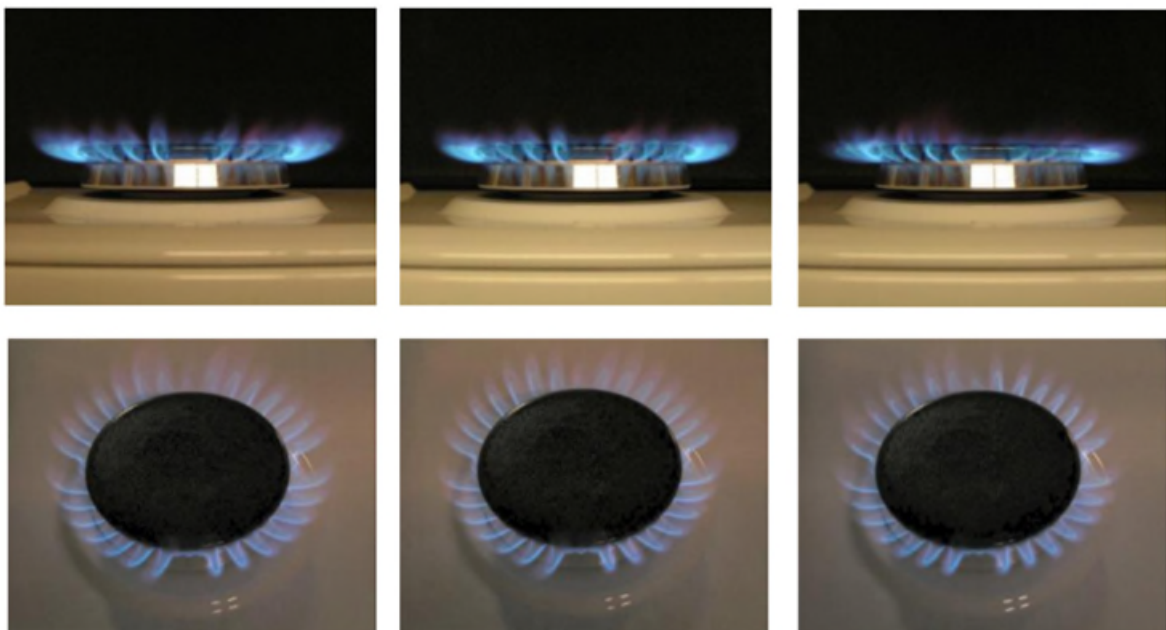


Figure 5 Gas cooker fuelled by hydrogen (up to 20%) blend with natural gas where hydrogen content of gas is increasing.⁵⁷

For 10% hydrogen blends in natural gas, the flame emissivity is like that of 100% natural gas. There is no

⁵⁵ (Wu, 2015)

⁵⁶ (Kippers, 2011)

⁵⁷ (Kippers, 2011)

identified increased risk associated with the flame colour for addition of 10% hydrogen to natural gas.

4.4 FLAME STABILITY

Flame stability is the balance between the velocities of unburned combustible gases passing through the burner ports to the flame speed (rate of expansion of flame front) of the combusting mixture.⁵⁸ The stability of a flame can be characterised by considering the process of light back and flame lift.⁵⁹

4.4.1 Light back (flashback)

Light back or flashback occurs when the gas velocity becomes lower than the burning velocity due to flame propagation within the boundary layer, core flow or because of combustion instabilities.⁶⁰ The avoidance of light back is one of the most important safety considerations during appliance design.⁶¹ Light back can cause damage and increase the risk of failure to a gas appliance.

Pure hydrogen has a laminar flame speed that is about four times the flame speed of typical natural gas. Its turbulent flame speed and resistance to hydrodynamic strain are also greater.⁶²

To ensure a design is safe, it must address two requirements for light back:

1. Under steady state conditions, the flame speed must nowhere exceed the gas flow velocity. This critical phenomenon is called flame propagation.
2. Under transient conditions, the flame must be extinguished in the burner once the transience is over. In this case, the critical phenomenon is called flame extinction.

Light back is primarily an issue with pre-mixed burners. It is interesting to note that light back can occur naturally from events such as rapid reduction of loads in a gas turbine.

The risk of light back increases with the addition of any hydrogen due to the increase in laminar flame speed.

The risk of light back is dependent on the appliance design but for up to 10% it is expected that the chance of light back is minimal. However, testing of appliances will be required to confirm whether light back is an issue.

4.4.2 Flame lift (blow-off)

Flame lift or blow-off occurs when the air/gas mixture enters the burner port at too high a velocity and may cause the flame to extinguish, as it is lifted, or “blown-off”, from the port.

The risk of flame-lift is increased with the addition of hydrogen but varies from appliance to appliance. The risk of flame-lift for each appliance type is discussed later in this report.

International studies and previous research suggest that for low concentrations of hydrogen, the risk of flame lift is negligible.⁶³ However, due to the difference in operating conditions, appliance design and testing between Australian and European appliances the results are not directly representative of testing under Australian appliance operating conditions. Testing of appliances in operation in Australia at Australian operating conditions will be required to understand if the risk of flame lift is increased at up

⁵⁸ (Gattej, 2008)

⁵⁹ (Jones & Al-Masry, 2018)

⁶⁰ (Plee & Mellor, 1978)

⁶¹ (Jones & Al-Masry, 2018)

⁶² (Cemal Benim & Syed, 2014)

⁶³ (Hawksworth & McCluskey, 2019)

10%.

4.5 MATERIALS

Addition of up to 10% hydrogen in natural gas affects the performance and characteristics of materials in both the appliance and for the installation.

Combustion affects materials through damage mechanisms including blistering, cracking, baking and melting. These issues are generally common to any gas combustion application and are well understood by burner and appliance manufacturers.

Hydrogen reduces the service life of metallic components such as pipework and valves through specific damage mechanisms that include embrittlement, blistering, hydrogen attack and cracking.⁶⁴

This section summarises the implications 10% hydrogen to materials.

4.5.1 Embrittlement

Embrittlement is the deterioration of the mechanical properties of carbon steels from the addition of hydrogen.⁶⁵ The susceptibility of steels to hydrogen embrittlement depends on three factors:

- Environment:
 - Hydrogen partial pressure
 - Temperature
 - Gas impurities
- Materials:
 - Composition
 - Microstructure
- Static and cyclic stress:
 - Geometry
 - Load cycle frequency

Embrittlement is a risk at low hydrogen concentrations but this risk reduces as the pressure or internal stress level decreases. For distribution networks designed to 20% of specified minimum yield stress (SMYS) using low strength steels, the risk of embrittlement with up to 10% is negligible.

For up to 10% hydrogen, steels in high-pressure application (above 6MPa) and/or at high stress levels (>20% SMYS) should be reviewed for the risk of embrittlement. Additionally, high strength steels used in any concentration of hydrogen service will require assessment for risk of embrittlement.

Embrittlement is only a credible risk in carbon steels and is not applicable to other materials.⁶⁶

4.5.2 Hydrogen assisted fatigue

Carbon and low alloy steels show accelerated fatigue crack growth and degradation in fatigue endurance limits when exposed to hydrogen even at relatively low pressures. The accelerated fatigue crack growth is more pronounced at ambient temperatures and becomes less severe at elevated temperatures.

The presence of hydrogen reduces the threshold cyclic stress intensity factor (K_{th}) as well as fatigue life, thus fatigue cracking will be a concern if the piping experiences pressure fluctuations.

⁶⁴ (Louthan, 2008)

⁶⁵ (Barthelemy, 2005)

⁶⁶ (Energy Pipelines Cooperative Research Centre, 2017)

4.5.3 High temperature hydrogen attack

High temperature hydrogen attack (HTHA) is the interaction between hydrogen that dissolves into steel and the carbon in the steel that is presented as either interstitial carbon or, more likely, carbides.⁶⁷ The carbon and the hydrogen then react to form methane that cannot diffuse out of the bulk of the material, due to the large size of the methane molecule. The entrapped methane then collects at microstructural features, such as grain boundaries where it may precipitate and form methane-filled bubbles. These bubbles grow and coalesce until fissures form, which leads to failures, generally intergranular in character.⁶⁸

To aid the understanding of HTHA the American Petroleum Institute (API) released *API Recommended Practice 941 - Steels for hydrogen service at elevated temperatures and pressures in petroleum refineries and petrochemical plants – 2004*.⁶⁹ This recommended practice manual provides a best practice guide for steels used in hydrogen service. Nelson curves quantify the safe operating limits of steels in hydrogen service.

The risk of HTHA increases with increasing temperature, increasing exposure time and increasing hydrogen partial pressure. Generally, increased risks of HTHA are not observed until temperatures exceed 204°C; this is also dependent on the steel used. However, depending on the steel the maximum allowable partial pressure can be as low as 100 psi (689 kPa) for carbon steel.⁷⁰

For low temperature and low-pressure applications such as domestic and commercial appliances there is no increased risk of HTHA. For industrial applications, particularly those that use natural gas as a feedstock at elevated pressures and temperatures, the risk of HTHA, could increase. However, due to the relatively low partial pressure of hydrogen in these applications at up to 10% hydrogen, these impacts are expected to be negligible.

Industrial users of natural gas, particularly those using natural gas as a feedstock, should review the risk of HTHA. Generally, for carbon steel, this will be in applications where temperatures exceed 204°C and partial pressure of hydrogen exceed 100 psi (689 kPa).

HTHA is only a risk in steels; elastomers, polymers, copper, and other non-metallic materials are not impacted.

4.5.4 Leakage

Losses of gas can occur in two ways:

- permeation through the material (including seals); and
- leakage through joints, fittings and connections.

4.5.4.1 PERMEATION

Permeation is a phenomenon where the gas molecules permeate (pass) through a material. Due to the size of the molecule, hydrogen permeation is unavoidable through any material. However, the rate is dependent on the type of material, condition, and the operating pressure. Although permeation exists, the rate of permeation at the operating pressure of the distribution network makes it technically and economically negligible with no increase in safety risk.⁷¹

⁶⁷ (Shewmon, 1985)

⁶⁸ (Weiner, 1961)

⁶⁹ (American Petroleum Institute, 2004)

⁷⁰ (American Petroleum Institute, 2004) Figure 1

⁷¹ (Melaina & Antonia, 2013)

For steels with hydrogen of up to 10%, the increased permeation is considered negligible and there are no additional risks.⁷²

For Polyethylene (PE), Polyvinyl Chloride (PVC), and Polyamine (PA) hydrogen permeation has been reviewed by multiple studies. Table 24 provides a summary of plastic testing projects completed.

Table 24 Summary of material testing studies

Project	Materials	Condition	Summary and results
PolyHYtube ⁷³	PE100 PA11	New Aged	<p>On different experimental devices, the permeability coefficient of hydrogen through PE100 and PA11 was determined in different representative conditions of the pipe line (pressure, temperature, hydrogen content, geometry of the sample).</p> <p>The effect of ageing in a hydrogen environment was studied. The study showed that no degradation of the barrier properties of the PE100 or the PA11 system was observed after more than one year of ageing in various conditions. The same conclusion was drawn for the aspects of the mechanical behaviour investigated here, i.e. tension, creep and ductile fracture, in both as-received and aged materials.</p>
NaturalHy ⁷⁴	PE 63 PE 80 PE 100 PCV-CPE	New Aged	<p>In this investigation, pipes and assemblies were tested at the operating temperatures and pressures with hydrogen/methane mixture in order to more precisely value the permeation of hydrogen through the plastic pipe in the natural gas distribution network. The summary of results from this study found:</p> <ul style="list-style-type: none"> • There is an incubation time for methane to diffuse through the pipe, while the incubation time for hydrogen is close to zero. • The permeation rate of methane and hydrogen increases with the increase of the internal pressure. • The permeation coefficient of hydrogen is 4 to 5 times greater than that of methane in the hydrogen/methane mixture, even if the hydrogen partial pressure is lower by an order of magnitude than that of methane in the mixture. • The absolute values of methane loss calculated for three types of PE piping materials are far lower than the extrapolated data. • The aging of the pipes seems to have no significant influence on the permeation coefficients in these experimental conditions

4.5.4.2 THROUGH JOINTS, FITTING AND CONNECTIONS

Leakage is caused by hydrogen escaping through a hole or a crack in seals, joints, fitting and connections. The smaller molecule size means that fittings that may have had enough sealing pressure for natural gas

⁷² (Melaina & Antonia, 2013)

⁷³ (Klopffer, 2010)

⁷⁴ (Gas Technology Insitute , 2010)

may not be “tight” enough for hydrogen. The high mobility of hydrogen results in lack of stratification and high homogeneity when hydrogen is blended with natural gas and significantly reduces this likelihood, particularly at lower gas distribution pressures.

Table 25 Suitability of joints, fitting and connections

Type	Implication of 10% hydrogen
Welded	Negligible. Providing the connection is in good condition
Flanged	Dependent on the operating conditions, materials and installation quality. Individual assessment required, however, for low-pressure applications these are likely suitable.
Threaded	Dependent on the operating conditions, materials and installation quality. Individual assessment required, however, for low-pressure applications these are likely suitable.
Screwed	Dependent on the operating conditions, materials and installation quality. Individual assessment required, however, for low-pressure applications these are likely suitable.
Capillary Joints	Dependent on the operating conditions, materials and installation quality. Individual assessment required, however, for low-pressure applications these are likely suitable.
Compression Fittings	Negligible. Providing the connection is in good condition
Solvent Cement	Lack of information available. Further investigation is required

Table 25 provides a high-level summary of the suitability of joint and fitting used in natural gas applications. The risk of leakage in fittings, joints and connections increases with 10% hydrogen but the amount is dependent on the operating conditions, materials and installation quality. It is required that the impact of 10% hydrogen to fittings, joints and connections be reviewed on an individual basis.

4.5.5 Summary

Table 25 provides a summary of the impacts and assessments required for commonly found materials that were identified downstream of the consumer billing meter.

Table 26 Summary of impacts to materials of up to 10% hydrogen

	Leakage - Permeability	Leakage - (through fittings, joints and connections)	Embrittlement	High temperature hydrogen attack
Plastic (PE, PA, PVC)	Assess when: <ul style="list-style-type: none"> • Aged/poor condition 	Assess when: <ul style="list-style-type: none"> • Solvent cement • Mechanical compression fitting • Flanged • Threaded • Screwed 	Negligible	Negligible
Steel	Negligible	Assess when: <ul style="list-style-type: none"> • Flanged • Screwed • Threaded 	Assess when: <ul style="list-style-type: none"> • High operating pressure (>3MPa), and/or • High operating stress (>20% SMYS) and/or • High strength steels 	Assess when: <ul style="list-style-type: none"> • Operating temperature over 205°C, and/or • Hydrogen partial pressure over 100 psi
Copper	Negligible	Assess	Negligible	Negligible

	Leakage - Permeability	Leakage - (through fittings, joints and connections)	Embrittlement	High temperature hydrogen attack
Cast Iron	Negligible	Assess	Negligible	Negligible
Brass	Negligible	Assess	Negligible	Negligible
Elastomers	Assess	N/A ⁷⁵	Negligible	Negligible

This summary is high-level, and it is expected that further investigation and testing will be required.

4.6 RISK AND SAFETY

The following section outlines the implications to risk and safety of up to 10% hydrogen to appliances and installations.

4.6.1 Flammability limit

The lower flammability limit (LFL) and upper flammability limit (UFL), describe the concentration of a gas mixture in air within which an explosive gas atmosphere will be formed.⁷⁶ Table 27 gives the LFL and UFL for hydrogen/methane blends.

Table 27 Flammability limits of hydrogen/methane blends

Gas composition	LFL (%)	UFL (%)
100% H ₂	4.00	77.00
10% H ₂ / 90% CH ₄	4.36	18.44
100% CH ₄	4.40	17.00

The implication of an expanded flammability range of a gas mixture is an expanded extent of hazardous area zone – that is the increase in size of the zone in which a potentially explosive atmosphere may be formed.⁷⁷

The extent of hazardous area zones is typically calculated based on a fraction of gas mixture LFL (commonly 50% or less if the gas composition is considered more variable). The extent of hazardous area zones calculated using 10% hydrogen with natural gas will be slightly larger than that calculated using pure natural gas due to the lower LFL. The effect of the lower LFL is minimal (less than 5% difference for a 10% blend), and within typical conservatism used in hazardous area extent calculations (50%).

4.6.2 Auto ignition temperature

The auto-ignition temperature is the minimum temperature of a hot surface that can ignite a flammable mixture.

The auto-ignition temperatures of methane and hydrogen are very similar. Table 28 provides a comparison of the auto ignition temperatures for hydrogen and methane.

⁷⁵ Elastomers are used in seals for joints

⁷⁶ (Standards Australia - AS/NZS 60079.10.1, 2009) section 3.17 and section 3.18

⁷⁷ (Standards Australia - AS/NZS 60079.10.1, 2009)

Table 28 Auto ignition temperature⁷⁸

Gas composition	Auto ignition temperature (°C)
100% H ₂	560
100% CH ₄	600

For 10% hydrogen in natural gas the auto-ignition temperature is slightly lower than that of 100% methane.

4.6.3 Flame sensors and controls

All gas appliances employ some form of flame detection; depending on the appliance, there is a variety of types for sensing and controlling.⁷⁹

In the technical review it was identified addition of hydrogen to natural gas will:

1. Increase the flame temperature,
2. Decrease the flame length, and
3. Change the flame shape.

For up to 10% hydrogen, these effects are not expected to impact existing flame sensors, ionisation and controls.⁸⁰

Where flame detection devices are required natural gas and hydrogen flame detectors are readily available but existing installations are considered unlikely to be impacted if the hydrogen concentration is limited to 10%.

4.6.4 Leak detection

Accurate gas detection is a fundamental requirement for the safe operation of a gas distribution network.⁸¹ Certain industrial users may have gas detection instrumentation designed to shut down or isolate sections of plant when the concentration of an explosive gas mixture in air reaches a fraction of lower explosive limit (LEL).

Gas leak detection devices designed for natural gas may not be accurate for mixtures of natural gas and up to 10% hydrogen. Some gas detection devices will be more sensitive to hydrogen than natural gas while others are not sensitive to hydrogen at all and will only detect the methane content. For detecting both hydrogen and methane, leak detection devices using semiconductors are generally considered suitable.⁸²

Generally, gas detection is based on accurately detecting a gas mixture based on calibration with a known gas such as methane or ethane and there is always variability in the measured flammable gas concentration of actual gas mixtures. Alarm limits are often set well below actual LEL at 5-10% for alarming purposes and often at values such as 40% of the LEL for automated shutdown and isolation systems. Based on this it is unlikely concentrations of up to 10% hydrogen will affect the effectiveness of gas detection systems.

⁷⁸ (GPA Engineering, 2019)

⁷⁹ (Health and Safety Laboratory, 2015)

⁸⁰ (Energy Pipelines Cooperative Research Centre, 2017)

⁸¹ (Isaac, 2019)

⁸² (EPCRC, 2017)

4.6.5 Gas build-up

Accumulation of gas in buildings is considered a significant risk. Hydrogen has the potential to increase the risk profile due to the wider flammability range, lower ignition energy, and higher mobility of the gas.

Previous studies have found that for 10% hydrogen in natural gas the small change in hazardous area and different gas combustion characteristic do not change the risk profile from 100% natural gas.^{83 84}

Gas build-up in buildings for 10% hydrogen in natural gas blend in domestic or industrial premises is like natural gas and does not present a significant change in risk.

4.6.6 Minimum ignition energy

Minimum Ignition Energy (MIE) is the energy that is required to bring a gas to a temperature that will allow combustion.⁸⁵

Table 29 gives the theoretical minimum ignition energy for pure gases.

Table 29 Minimum Ignition Energy of pure gases⁸⁶

Gas Composition	Minimum Ignition Energy (mJ)
methane (100% CH ₄)	0.29
hydrogen (100% H ₂)	0.019

It is reported that the MIE decreases proportionally with the increase of the hydrogen fraction.⁸⁷ For a 10% hydrogen blend it is expected that the MIE will be similar to that of a pure methane blend.

4.7 SUMMARY

Table 30 provides a summary of the technical implications of adding up to 10% hydrogen to natural gas. For some parameters, the data for natural gas was not available; a 10% hydrogen / 90% methane blend is used as a representation.

Table 30 Summary of implications for 10% hydrogen in natural gas/methane

Parameter	Impact	Summary of implications
Gas Quality	Technical Commercial	<ul style="list-style-type: none"> The Wobbe Index (WI) decreases by approximately 2% The specific gravity (SG) decreases by approximately 10% The methane number in 10% hydrogen / 90% methane reduces by 10% to 90
Combustion	Technical Safety	<ul style="list-style-type: none"> Without modification, the air/gas ratio will be leaner The volumetric LHV decreases slightly The amount of moisture during produced during combustion slightly increases The increase in risk of yellow tipping is negligible Without modification or tuning NO_x will likely slightly increase, CO₂ will likely slightly decrease, and CO will

⁸³ HyDeploy

⁸⁴ (NREL, 2017)

⁸⁵ (Mathurkar, 2009)

⁸⁶ (Mathurkar, 2009)

⁸⁷ (Hankinson, 2009)

Parameter	Impact	Summary of implications
		likely slightly increase
Flame Characteristics	Technical Safety	<ul style="list-style-type: none"> • The adiabatic flame temperature slightly increases • The laminar flame speed will slightly increase • Slight drop in radiative heat transfer • The flame length slightly decreases • There is negligible impact to the flame colour
Flame Stability	Technical Safety	<ul style="list-style-type: none"> • The risk of light back slightly increases • The risk of flame lift slightly increases
Materials	Technical Safety	<ul style="list-style-type: none"> • The risk of embrittlement in steels increases, particularly in carbon steels under high pressure and high stress • The risk of hydrogen assisted fatigue increases for piping system that are experience significant pressure fluctuations. • The risk of high temperature hydrogen attack increases at temperatures over 204°C and hydrogen partial pressures above 100 psi • The risk of leakage slightly increases via: <ul style="list-style-type: none"> ○ Permeation through plastics and elastomers ○ Leakage through some joints, seals and fittings
Risk and Safety	Technical Safety	<ul style="list-style-type: none"> • The flammability limits (UFL and LFL) are slightly wider • The auto ignition temperature is slightly lower • The current flame detectors and control are likely suitable for up to 10% hydrogen • The current leak detection equipment is likely suitable for up to 10% hydrogen • The current ventilation and hazardous area zones are likely suitable for up to 10% hydrogen • The minimum ignition energy (MIE) is slightly lower leading to slightly higher risk of spontaneous ignition

5 TECHNICAL IMPACT ON GAS-USERS

This section provides a desktop review of the technical impacts of up to 10% hydrogen on Type A and Type B gas appliances, feedstock users, installations and compressed natural gas (CNG).

5.1 TYPE A APPLIANCES

Table 31 provides a desktop review of the potential technical impacts of up to 10% hydrogen to Type A (domestic) appliances.⁸⁸

Table 31 Technical impacts of up to 10% hydrogen on Type A appliances

Component	Function	Impact on component of up to 10% hydrogen	Technical risk
Combustion			
Burner	Site of combustion Controls safe and efficient combustion and flame	Relevant implications that may impact the performance and safety of this component: <ul style="list-style-type: none"> Slightly increased flame speed Slightly increased flame temperature Which, for up to 10% hydrogen in natural gas blends may lead to: <ul style="list-style-type: none"> Potential light back of combustible gas behind burner surface. Further testing is required to understand the likelihood and increased risk although it is likely that existing component will be suitable Possibly higher NO_x but it is likely that existing component will be suitable 	It is likely that there will be no increased risk, but further testing of flame stability is recommended.
Igniter	Ignites gas/air mixture at burner	Relevant implications that may impact the performance and safety of this component: <ul style="list-style-type: none"> Slightly lower ignition energy. Slightly wider flammability limit. Which, for up to 10% hydrogen in natural gas blends is not likely to affect the existing component or change the risk profile.	No increased risk.
Pilot light	Flame to support main burner operation	Relevant implications that may impact the performance and safety of this component: <ul style="list-style-type: none"> Slightly increased flame speed Which, for up to 10% hydrogen in natural gas blends may lead to: <ul style="list-style-type: none"> Change in the size and stability of pilot light although it is likely that existing component will be suitable 	It is likely that there will be no increased risk but further testing of the pilot light is recommended.
Gas valve	Gas shut-off and throttling	Relevant implications that may impact the performance and safety of this component: <ul style="list-style-type: none"> Slightly increased permeation and leakage due to the smaller hydrogen molecule Which, for up to 10% hydrogen in natural	It is likely that there will be no increased risk but further testing of leakage in the gas valve is




⁸⁸ Commercial, regulatory and economic impacts were not considered as part of this study.

Component	Function	Impact on component of up to 10% hydrogen	Technical risk
		<p>gas blends may lead to:</p> <ul style="list-style-type: none"> Potential for hydrogen to leak through valve seals, Further investigation is required although it is likely that existing component will be suitable 	recommended.
Heat transfer and exhaust			
Heat exchanger Flame shield Internal panel	Transfers heat from combustion zone to provide usable heat output	<p>Relevant implications that may impact the performance and safety of this component:</p> <ul style="list-style-type: none"> Slightly increased flame temperature Slightly different IR/UV emission characteristics Slightly shorter flame length Slightly increased quantity water vapour in combustion products <p>Which, for up to 10% hydrogen in natural gas blends is not likely to affect the existing component or change the risk profile.</p>	No increased risk
Sump	Collects condensate from heat exchanger	<p>Relevant implications that may impact the performance and safety of this component:</p> <ul style="list-style-type: none"> Slightly increased quantity water vapour in combustion products <p>Which, for up to 10% hydrogen in natural gas blends may lead to:</p> <ul style="list-style-type: none"> The additional humidity could cause additional condensation that could promote the growth of mould. For un-flued appliances, the impacts on the appliance and risk of increased mould should be further investigated, although it is likely that existing component will be suitable. For flued appliances, it is likely that existing components will be suitable Potential for hydrogen to leak through valve seals although it is likely that existing component will be suitable 	It is likely that there will be no increased risk but further investigation of the impacts of the increased water vapour produced during combustion is recommended.
Flue	Ensures release of burnt and "unburnt" gas to the external environment	<p>Relevant implications that may impact the performance and safety of this component:</p> <ul style="list-style-type: none"> Slightly increased flame temperature Slightly increased quantity water vapour in combustion products <p>Which, for up to 10% hydrogen in natural gas blends may lead to:</p> <ul style="list-style-type: none"> Exhaust gas will slightly increase in temperature although it is likely that existing component will be suitable Slightly more water vapour produced. For un-flued appliances, the impacts on the appliance and 	It is likely that there will be no increased risk but further investigation of the impacts of the increased water vapour produced during combustion is recommended.

Component	Function	Impact on component of up to 10% hydrogen	Technical risk
		<p>risk of increased mould should be further investigated, although it is likely that existing component will be suitable. For flued appliances, it is likely that existing components will be suitable</p> <ul style="list-style-type: none"> Increased heat transfer to other components within appliance and potentially to building fabric outside appliance although it is likely that existing component will be suitable. 	
Controls			
Flame sensor	Safety device used to regulate gas fuel released to the burner	<p>Relevant implications that may impact the performance and safety of this component:</p> <ul style="list-style-type: none"> Slightly increased flame temperature Slightly shorter flame length Slightly different flame shape <p>Which, for up to 10% hydrogen in natural gas blends is not likely to affect the existing component or change the risk profile.</p>	No increased risk
Ionisation sensor	Safety device used to regulate gas fuel released to the burner	<p>Relevant implications that may impact the performance and safety of this component:</p> <ul style="list-style-type: none"> Slightly decreased number of hydrocarbon ions <p>Which, for up to 10% hydrogen in natural gas blends is not likely to affect the existing component or change the risk profile.</p>	No increased risk
Automatic and manual controls	Automatic regulation of appliance heat output	No significant issues.	No increased risk
Frame and appliance pipework (to the appliance limit)			
Pipework/manifold	Distributes fuel gas in appliance	<p>Relevant implications that may impact the performance and safety of this component:</p> <ul style="list-style-type: none"> Slightly increased permeation and leakage due to the smaller hydrogen molecule Increase in the risk of embrittlement <p>Which, for up to 10% hydrogen in natural gas blends may lead to:</p> <ul style="list-style-type: none"> Slightly increased leakage rate through joints, fittings and connections Slightly increased permeation through plastic piping Increased risk of embrittlement in steels, which is dependent on operating conditions <p>Due to the low operating pressures in Type A appliances, for up to 10% hydrogen in natural gas blends is unlikely to affect the</p>	No increased risk

Component	Function	Impact on component of up to 10% hydrogen	Technical risk
		existing component or change the risk profile.	
Frame (casing)	Protects components and provides casing which could allow unburnt gases to accumulate	Relevant implications that may impact the performance and safety of this component: <ul style="list-style-type: none"> Slightly increased permeation and leakage due to the small molecule Which, for up to 10% hydrogen in natural gas blends may lead to: <ul style="list-style-type: none"> Outer casing could allow a combustible gas mixture to form although is not likely to affect the existing component or change the risk profile 	No increased risk

Each component was assigned a technical risk based on the following coding:

	There is no significant increase in risk for the component with addition of up to 10% hydrogen. In principle (subject to functional checks), the existing component could be used.
	Addition of up to 10% hydrogen requires further review of the impacts to this component, although it is likely that as is, the component will be suitable.
	The component technical not suitable or is unsafe with 10% hydrogen and will require further work.

5.1.1 Summary and recommendation

A desktop review of the technical suitability of Type A (domestic) appliances for up to 10% hydrogen blended with natural gas was completed. It found that overall, the appliances are likely to be suitable but further investigation is recommended to confirm that:

- The slight increase in flame speed does not lead to any increased safety risks due to flame instability. This is both the main burner and the pilot light (if applicable)
- The slight increase in water vapour produced increase in condensation in the sump of flue of the appliance (if the appliance has a “flue”) does not lead to an increased safety risk.
- The slight increase in leakage through seals and joints in the gas valve does lead to increased safety risks.

Although it is expected that these components will be suitable for up to 10% hydrogen, it is recommended that further assessment of the technical impacts on new and existing Type A appliances be completed, in particular, the impacts to flame stability, leakage rates through the gas valve and the consequences of increased moisture production from combustion. The results of this recommendation will assist to confirm there are no additional safety, integrity and operational risks associated with the addition of up to 10% hydrogen into the gas distribution networks.

This recommendation should be implemented via appliance testing programmes, and testing should be completed before hydrogen is added to the natural gas distribution network.

This recommendation will require involvement from appliance manufacturers, appliance regulators and appliance testing laboratories.

It should however be noted that there is on-going appliance testing in Australia. The FFCRC are currently testing a range of 17 gas domestic gas appliances to the test methods outline in AS/NZS 5236.0 for a gas quality of 10% hydrogen and 90% natural gas. This testing has increased the proportion of hydrogen in the N_b test gas to approximately 21.7% to ensure that safety margins are maintained. The results of this testing are expected to help inform the suitability of current gas appliances for up to 10% hydrogen and should be leveraged to avoid duplication of efforts in this area.

5.2 TYPE B APPLIANCES

Type B appliances are appliances for which a certification scheme does not exist. This means they are limited production, generally “one off” appliances. Although, the final use of gas may vary between different appliances there are commonalities between the fuel and burner system. Table 32 provides a summary of the potential impacts of up to 10% hydrogen on the fuel and burner systems of a Type B appliance.

Table 32 Impacts up to 10% hydrogen on Type B fuel and burner systems

Component	Function	Impact on component of up to 10% hydrogen	Technical risk
Combustion system			
Main Burner(s)	Allows for the introduction of fuel and air a combustion chamber at the desired velocity, turbulence, and air/gas ratio to establish and maintain stable combustion conditions.	<p>Relevant implications that may impact the performance and safety of this component:</p> <ul style="list-style-type: none"> Slightly increased flame speed Slightly shorter flame length Slightly increased flame temperature Slight decrease in the Wobbe Index Slightly different UV/IR characteristics <p>Which, for up to 10% hydrogen in natural gas blends may lead to:</p> <ul style="list-style-type: none"> Increased risk of light back and flame lift in the burner although it is likely that existing component will be suitable. Possible higher NO_x but it is likely that existing component will be suitable although it is expected to be negligible and manageable by tuning. Possible slight increase in CO but slight decrease in CO₂. It is likely that existing component will be suitable although it is expected to be negligible and manageable by tuning. Slight decrease overall burner efficiency although it is expected to be negligible and manageable by tuning. Burner de-rated due to lower Wobbe Index 	<p>Likely to see a small impact to overall efficiency and potential increase in emissions and risk of light back.</p> <p>However, likely manageable via tuning and minor modifications.</p>
Injector	Causes the air to mix with a stream of gas. In the case of an aerated burner it incorporates an orifice discharging gas into the mixing tube or the throat.	<p>Relevant implications that may impact the performance and safety of this component:</p> <ul style="list-style-type: none"> Slight decrease in the Wobbe Index. Slightly increased flame speed <p>Which, for up to 10% hydrogen in natural gas blends may lead to:</p> <ul style="list-style-type: none"> For injectors already at their limit this may require increasing the size of the injector. Generally, sizing of injectors includes a design margin that additional 	<p>Likely slight impact to efficiency.</p> <p>However, likely manageable via tuning and minor modifications.</p>

Component	Function	Impact on component of up to 10% hydrogen	Technical risk
		capacity is available for future uncertainty so it is likely that the current injectors will be suitable for up to 10% hydrogen.	
Igniter ⁸⁹	Used to light a pilot or main burner. This is dependent of the size of the burner.	<p>Relevant implications that may impact the performance and safety of this component:</p> <ul style="list-style-type: none"> Slightly lower ignition energy Slightly wider flammability range <p>Which, for up to 10% hydrogen in natural gas blends is not likely to affect the existing component or change the risk profile.</p>	No increased risk.
Mixing blower	Is motor driven and on the suction side of the burner. This supplies the burner with the air and gas and generally has no controller.	<p>Relevant implications that may impact the performance and safety of this component:</p> <ul style="list-style-type: none"> Slightly increased permeation and leakage due to the smaller hydrogen molecule Increased risk of embrittlement. <p>Which, for up to 10% hydrogen in natural gas blends may lead to:</p> <ul style="list-style-type: none"> Increased leakage rates through seals, joints and fittings. Further investigation is required to confirm, however it is likely that existing component will be suitable. Premature failure of steel components due to embrittlement. Further investigation is required to confirm, however, it is likely that existing component will be suitable 	It is likely that there will be no increased risk but further investigation of the increased leakage rates and embrittlement is recommended.
Pilot	Provides ignition energy to light the main burner.	<p>Relevant implications that may impact the performance and safety of this component:</p> <ul style="list-style-type: none"> Slightly increased flame speed Slightly shorter flame length Slightly increased flame temperature Slight decrease in the Wobbe Index <p>Which, for up to 10% hydrogen in natural gas blends may lead to:</p> <ul style="list-style-type: none"> Increased risk of light back in the burner although it is likely that existing component will be suitable. Possible higher NO_x but it is likely that existing component will be suitable; risk is expected to be negligible and manageable by tuning Possible slight increase in CO but slight decrease in CO₂. However, it is likely that existing component 	<p>Likely to see a small impact to overall efficiency and potential increase in emissions and risk of light back.</p> <p>However, likely manageable via tuning and minor modifications</p>

⁸⁹ Often igniters and pilots are the same device

Component	Function	Impact on component of up to 10% hydrogen	Technical risk
		<p>will be suitable; risk is expected to be negligible and manageable by tuning.</p> <ul style="list-style-type: none"> Slight decrease overall burner efficiency. However, it is likely that existing component will be suitable although it is expected to be negligible and manageable by tuning. 	
Valve train assembly			
Valve train	<p>The valve train is a combination of valves, regulators, pipe pieces and unions, immediately upstream of the burner, which form an integrated system for flow or pressure control and safe operator of the burner.</p>	<p>Relevant implications that may impact the performance and safety of this component:</p> <ul style="list-style-type: none"> Slightly increased permeation and leakage due to the smaller hydrogen molecule Increased risk of embrittlement. Slight decrease in Wobbe Index <p>Which, for up to 10% hydrogen in natural gas blends may lead to:</p> <ul style="list-style-type: none"> Increased leakage rates through seals, joints and fittings. Further investigation is required to confirm, however it is likely that existing component will be suitable. Premature failure of steel components due to embrittlement. Further investigation is required to confirm, however, it is likely that existing component will be suitable Increased permeation rates through plastic piping systems. Further investigation is required to confirm, however, it is likely that existing component will be suitable The slightly lower Wobbe Index means an increase flow through the components required to achieve the same heat input. It is likely that equipment has been sized with appropriate safety margin that there is unlikely to be an impact. 	<p>It is likely that there will be no increased risk but further investigation of the increased leakage rates, permeation rates and embrittlement is recommended.</p>
Isolation valve	<p>The isolating valve is required to be in close proximity to the appliance.</p>	<p>Relevant implications that may impact the performance and safety of this component:</p> <ul style="list-style-type: none"> Slightly increased permeation and leakage due to the smaller hydrogen molecule Increased risk of embrittlement. <p>Which, for up to 10% hydrogen in natural gas blends may lead to:</p> <ul style="list-style-type: none"> Increased leakage rates through seals, joints and fittings. Further investigation is required to confirm, however it is likely that existing component will be suitable. Premature failure of steel 	<p>It is likely that there will be no increased risk but further investigation of the increased leakage rates, permeation rates and embrittlement is recommended.</p>

Component	Function	Impact on component of up to 10% hydrogen	Technical risk
		<p>components due to embrittlement. Further investigation is required to confirm, however, it is likely that existing component will be suitable</p> <ul style="list-style-type: none"> Increased permeation rates through plastic piping systems. Further investigation is required to confirm, however, it is likely that existing component will be suitable 	
Safety shut-off valve	<p>Used to shut off gas to an appliance when a signal is generated indicating the approach of an unsafe condition. Must complete with AS 4629.</p>	<p>Relevant implications that may impact the performance and safety of this component:</p> <ul style="list-style-type: none"> Slightly increased permeation and leakage due to the smaller hydrogen molecule Increased risk of embrittlement. <p>Which, for up to 10% hydrogen in natural gas blends may lead to:</p> <ul style="list-style-type: none"> Increased leakage rates through seals, joints and fittings. Further investigation is required to confirm, however it is likely that existing component will be suitable. Premature failure of steel components due to embrittlement. Further investigation is required to confirm, however it is likely that existing component will be suitable Increased permeation rates through plastic piping systems. Further investigation is required to confirm, however, it is likely that existing component will be suitable <p>Additionally, AS 3814 requires the maximum leakage between the safety shut off valves be 0.05% the maximum gas rate through the system.</p>	<p>It is likely that there will be no increased risk but further investigation of the increased leakage rates, permeation rates and embrittlement is recommended.</p>
Regulator	<p>Used to control flow and/or pressure to the burner (or group of burners).</p>	<p>Relevant implications that may impact the performance and safety of this component:</p> <ul style="list-style-type: none"> Slightly increased permeation and leakage due to the smaller hydrogen molecule Increased risk of embrittlement. Slightly decreased Wobbe Index <p>Which, for up to 10% hydrogen in natural gas blends may lead to:</p> <ul style="list-style-type: none"> Increased leakage rates through seals, joints and fittings. Further investigation is required to confirm, however it is likely that existing component will be suitable Premature failure of steel components due to embrittlement. Further investigation is required to confirm, however, it is likely that existing component will be suitable Increased permeation rates 	<p>It is likely that there will be no increased risk but further investigation of the increased leakage rates, permeation rates and embrittlement is recommended.</p>

Component	Function	Impact on component of up to 10% hydrogen	Technical risk
		<p>through plastic piping systems. Further investigation is required to confirm, however it is likely that existing component will be suitable</p> <ul style="list-style-type: none"> The lower volumetric energy density means that to deliver the same energy the pressure is required to be increased. Further investigation is required to confirm, however, it is likely that existing component will be suitable 	
Pipework	The piping, tubing and connections that join and seal key equipment.	<p>Relevant implications that may impact the performance and safety of this component:</p> <ul style="list-style-type: none"> Slightly increased permeation and leakage due to the smaller hydrogen molecule Increased risk of embrittlement. <p>Which, for up to 10% hydrogen in natural gas blends may lead to:</p> <ul style="list-style-type: none"> Increased leakage rates through seals, joints and fittings. Further investigation is required to confirm, however it is likely that existing component will be suitable. Premature failure of steel components due to embrittlement. Further investigation is required to confirm, however, it is likely that existing component will be suitable Increased permeation rates through plastic piping systems. Further investigation is required to confirm, however it is likely that existing component will be suitable 	It is likely that there will be no increased risk but further investigation of the increased leakage rates, permeation rates and embrittlement is recommended.
Gas filter	Installed within the valve train to remove contaminants from the gas stream.	<p>Relevant implications that may impact the performance and safety of this component:</p> <ul style="list-style-type: none"> Slightly increased permeation and leakage due to the smaller hydrogen molecule Increased risk of embrittlement Slight decrease in the Wobbe Index <p>Which, for up to 10% hydrogen in natural gas blends may lead to:</p> <ul style="list-style-type: none"> Increased leakage rates through seals, joints and fittings. Further investigation is required to confirm, however it is likely that existing component will be suitable. Premature failure of steel components due to embrittlement. Further investigation is required to confirm, however it is likely that existing component will be suitable Increased permeation rates through plastic piping systems. 	It is likely that there will be no increased risk but further investigation of the increased leakage rates, permeation rates and embrittlement is recommended.

Component	Function	Impact on component of up to 10% hydrogen	Technical risk
		<p>Further investigation is required to confirm, however it is likely that existing component will be suitable</p> <ul style="list-style-type: none"> Increased velocities and pressures across the component for equivalent energy throughput. Component must be rated to handle the increased operating pressure 	
Valve train enclosure	For some appliances, the valve train are within an enclosure.	<p>Relevant implications that may impact the performance and safety of this component:</p> <ul style="list-style-type: none"> Slightly different risk in ventilation and hazardous areas. <p>Which, for up to 10% hydrogen in natural gas blends is not likely to affect the existing component or change the risk profile.</p>	No increased risk.
Safety systems			
Flame sensor	A device that is sensitive to flame properties and initiates a signal when flame is detected.	<p>Relevant implications that may impact the performance and safety of this component:</p> <ul style="list-style-type: none"> Slightly increased flame temperature Slightly shorter flame length Slightly different flame shape Slightly different UV/IR characteristics <p>Which, for up to 10% hydrogen in natural gas blends is not likely to affect the existing component or change the risk profile.</p>	No increased risk.
High gas pressure device	A sensing device that is actuated when pressure rises above a pre-set value.	<p>Relevant implications that may impact the performance and safety of this component:</p> <ul style="list-style-type: none"> Slightly increased permeation and leakage due to the smaller hydrogen molecule Increased risk of embrittlement. <p>Which, for up to 10% hydrogen in natural gas blends may lead to:</p> <ul style="list-style-type: none"> Increased leakage rates through seals, joints and fittings. Further investigation is required to confirm, however it is likely that existing component will be suitable. Premature failure of steel components due to embrittlement. Further investigation is required to confirm, however, it is likely that existing component will be suitable Increased permeation rates through plastic piping systems. Further investigation is required to confirm, however it is likely that existing component will be suitable 	It is likely that there will be no increased risk but further investigation of the increased leakage rates, permeation rates and embrittlement is recommended.
Low gas pressure device	A sensing device that is	Relevant implications that may impact the performance and safety of this component:	It is likely that there will be no

Component	Function	Impact on component of up to 10% hydrogen	Technical risk
	actuated when the gas pressure falls below a pre-set value.	<ul style="list-style-type: none"> Slightly increased permeation and leakage due to the smaller hydrogen molecule Increased risk of embrittlement. <p>Which, for up to 10% hydrogen in natural gas blends may lead to:</p> <ul style="list-style-type: none"> Increased leakage rates through seals, joints and fittings. Further investigation is required to confirm, however it is likely that existing component will be suitable. Premature failure of steel components due to embrittlement. Further investigation is required to confirm however, it is likely that existing component will be suitable Increased permeation rates through plastic piping systems. Further investigation is required to confirm, however it is likely that existing component will be suitable 	increased risk but further investigation of the increased leakage rates, permeation rates and embrittlement is recommended.
Flame safeguard system	Is a system consisting of the flame detectors, associated circuitry, integral components, valve, and interlocks whose function is to shut off the fuel supply to the burner(s) in the event of ignition failure or flame failure.	<p>Relevant implications that may impact the performance and safety of this component:</p> <ul style="list-style-type: none"> Slightly increased flame temperature Slightly wider flammability limit. Slightly lower ignition energy. Slightly shorter flame length <p>Which, for up to 10% hydrogen in natural gas blends is not likely to affect the existing component or change the risk profile.</p>	No increased risk.
Valve leak detection unit	Used where shut-off valve requirements are met using valve proving.	<p>No significant issues.</p> <p>Could potentially require adjustment/retuning of setting if leakage past gas shut-off valves are impacted significantly, however, unlikely</p>	No increased risk.
Control system			
Burner management system	Fields devices, final control elements and the logic system, dedicated tom combustion safety and	<p>Relevant implications that may impact the performance and safety of this component:</p> <ul style="list-style-type: none"> Slightly increased flame speed Slightly shorter flame length Slightly increased flame temperature Slight decrease in the Wobbe Index Slight change in stoichiometric 	<p>Likely slight impact to appliance performance, operation and safety.</p> <p>This is expected to be manageable</p>

Component	Function	Impact on component of up to 10% hydrogen	Technical risk
	operator assistance in the starting, running and stopping of fuel burning equipment and for the preventing incorrect operation and damage of the fuel equipment.	composition Which, for up to 10% hydrogen in natural gas blends may lead to: <ul style="list-style-type: none"> Increased risk of light back Possible higher NO_x Possible slight increase in CO but slight decrease in CO₂. Slight decrease overall burner efficiency Slight change in the air/gas ratio Without tuning, the burner will operate at an over lower efficiency and safety parameters might be slightly changed. however, it is likely that existing system will still operate safety.	through tuning.
Damper	The adjustable device for controlling airflow in an appliance.	No significant issues.	No increased risk.
Air/gas ratio control	Could be via programmable BMS (see above), mechanical linkage between air/gas control valves, or gas proportioning regulator using combustion air reference.	Relevant implications that may impact the performance and safety of this component: <ul style="list-style-type: none"> Slight decrease in the Wobbe Index Slight change in stoichiometric composition Which, for up to 10% hydrogen in natural gas blends may lead to: <ul style="list-style-type: none"> Appliances may need to be re-tuned to ideal combustion conditions 	Likely slight impact to overall appliance efficiency. This is expected to be manageable through tuning.
Appliance housing and components			
Heat exchanger Flame shield Internal panels	Transfers heat from combustion zone to provide usable heat output.	Relevant implications that may impact the performance and safety of this component: <ul style="list-style-type: none"> Slightly shorter flame length Slightly higher adiabatic flame temperature Slighter lower radiant heat. Which, for up to 10% hydrogen in natural gas blends may lead to: <ul style="list-style-type: none"> Appliances that rely on radiant heat may see a slight decrease in performance. However, it is likely that this will be negligible Processes that are highly sensitive to temperature variation 	It is likely that there will be no increased risk. However, further investigation of the impact to temperature sensitive process is recommended.
Sump	Collects condensate.	Relevant implications that may impact the performance and safety of this component: <ul style="list-style-type: none"> Slightly increased quantity water vapour in combustion products Which, for up to 10% hydrogen in natural	No increased risk.

Component	Function	Impact on component of up to 10% hydrogen	Technical risk
		gas blends is not likely to affect the existing component or change the risk profile.	
Flue	Flues are designed to discharge combustion products.	<p>Relevant implications that may impact the performance and safety of this component:</p> <ul style="list-style-type: none"> Slightly increased flame temperature Slightly increased quantity water vapour in combustion products <p>Which, for up to 10% hydrogen in natural gas blends may lead to:</p> <ul style="list-style-type: none"> Exhaust gas will slightly increase in temperature although it is likely that existing component will be suitable Slightly more water vapour produced. For un-flued appliances, the impacts on the appliance and risk of increased mould should be further investigated, although it is likely that existing component will be suitable. For flued appliances, it is likely that existing components will be suitable Increased heat transfer to other components within appliance and potentially to building fabric outside appliance although it is likely that existing component will be suitable. <p>Note: Most Type B appliances are flued.</p>	It is likely that there will be no increased risk but further investigation of the impacts of the increased water vapour produced during combustion is recommended.
Process afterburner	A gas-fired appliance used specifically for the incineration of exhaust gases containing combustible gases or dust in concentration below the lower explosive limit.	<p>Relevant implications that may impact the performance and safety of this component:</p> <ul style="list-style-type: none"> Slightly increased flame speed Slightly shorter flame length Slightly increased flame temperature Slight decrease in the Wobbe Index <p>Which, for up to 10% hydrogen in natural gas blends may lead to:</p> <ul style="list-style-type: none"> Increased risk of light back in the burner although it is likely that existing component will be suitable. Possible higher NO_x but it is likely that existing component will be suitable. Risk is expected to be negligible and manageable by tuning Possible slight increase in CO but slight decrease in CO₂. It is likely that existing component will be suitable although risk is expected to be negligible and manageable by tuning 	<p>Likely to see a small impact to overall efficiency and potential increase in emissions and risk of light back.</p> <p>However, likely manageable via tuning and minor modifications.</p>

Component	Function	Impact on component of up to 10% hydrogen	Technical risk
		<ul style="list-style-type: none"> Slight decrease overall burner efficiency although risk is expected to be negligible and manageable by tuning 	

Each component was assigned a technical risk based on the following coding:

	There is no significant increase in risk for the component with addition of up to 10% hydrogen. In principle (subject to functional checks), the existing component could be used.
	There is no significant increase in risk for the component with addition of up to 10% hydrogen. In principle (subject to functional checks), the existing component could be used but may require minor modification or tuning .
	Addition of up to 10% hydrogen requires further review of the impacts to this component, although it is likely that as is, the component will be suitable.
	The component technical not suitable or is unsafe with 10% hydrogen and will require further work.

5.2.1 Summary and recommendation

A desktop review of the technical suitability of Type B (commercial and industrial) appliances for up to 10% hydrogen blended with natural gas was completed. It found that overall, the appliances are likely to be suitable but further investigation is required to confirm that:

- There is no significant increase in materials related safety risks from embrittlement, leakage (through permeation and leakage through joints, fittings and connections) and HTHA.
- The slight increase in flame speed does not lead to any increased safety risks due to flame instability.
- There are no significant technical or performance issues to appliances/process that are highly temperature sensitive.
- The slight increase in water vapour produced increase in condensation in the sump or flue of the appliance (if the appliance has a flue) with could lead to an increased safety risk. For Type B there are expected to be minimal appliances in this category.
- The slight increase in flame temperature does not increase NO_x above the allowable limit.

Although it is likely that these components will be suitable for up to 10% hydrogen, further investigation of the technical impacts to new and existing Type B appliances should be completed, in particular:

- **Detailed review of the materials used in Type B appliances and suitability assessment for 10% hydrogen/natural gas blend.**
- **Testing of Type B appliance burners to confirm that there are no increased safety impacts to flame stability. Testing of appliances with little or no tuning capabilities should be priority.**
- **Detailed review and identification of appliances/processes that are temperature sensitive and analysis of the impacts to these, in particular**
 - **Glassmakers**
 - **Brick works**
- **Review the impacts of increased NO_x to Type B appliances.**
- **Review the impacts of increase water vapour to un-flued appliances.**

The results of this further work will assist to confirm there are no additional safety, integrity and

operational risks associated with the addition of up to 10% hydrogen into the gas distribution networks.

This recommendation will require involvement from appliance manufacturers, appliance regulators and appliance testing laboratories. Further work by the FFCRC to confirm the suitability of Type B appliances with the addition of hydrogen will commence soon. The results of this testing, when available, should be leveraged to avoid duplication of efforts in this area and to further inform any future work.

5.3 FEEDSTOCK USERS

Previously, in certain industrial processes the need has arisen to raise or lower the temperature by admixture of another combustible gas.⁹⁰

During the desktop review as part of this study only ammonia was identified as a user of natural gas supplied by the natural gas distribution network.

Table 33 provides a summary of the potential technical impacts of up to 10% hydrogen to feedstock users of natural gas. Commercial and economic impacts are not considered as part of this study.

Table 33 Technical impact of up to 10% to feedstock users

Process	Impact of up to 10% hydrogen	Technical risk
Ammonia	<p>Relevant implications that may impact the performance and safety of this process:</p> <ul style="list-style-type: none"> Slight decrease in the Wobbe Index Slightly different UV/IR characteristics Slight increase in risk of embrittlement <p>Which, for up to 10% hydrogen in natural gas blends may lead to:</p> <ul style="list-style-type: none"> Slight increase in overall process efficiency Slight decrease in process afterburner efficiency although expected to be manageable by tuning 	<p>The addition of 10% Hydrogen will not affect the existing facilities.</p> <p>The natural gas is split into its constituents (including hydrogen) it is likely the process will become more efficient. Although optimising of the process and equipment may be required.</p> <p>Existing facilities are likely designed to manage the safety and materials risks of hydrogen.</p>

Each component was assigned a technical risk based on the following coding:

	There is no significant increase in risk safety for the user with addition of up to 10% hydrogen. In principle (subject to functional checks),
	There is no significant increase in risk for the user with addition of up to 10% hydrogen. In principle (subject to functional checks), the existing process may require minor modification or tuning .
	Addition of up to 10% hydrogen requires further review of the impacts to the user and may require major modifications.
	The addition of up to 10% hydrogen will impact the end users and make the process technically not suitable or is unsafe and will require further work.

5.3.1 Summary and recommendation

A desktop review of the technical suitability of feedstock users for up to 10% hydrogen blended with natural gas was completed. It found that overall, that the existing facilities supplied by the distribution network are likely suitable to handle up to 10% hydrogen blends. Further investigation is required to provide the confidence to confirm that all feedstock users types supplied have been identified.

A scoping study to identify feedstock all users supplied from the distribution network.

The results of this recommendation will further inform where there are additional safety, integrity

⁹⁰ (Jones & Lewis, 1931)

and operational risks associated with the addition of up to 10% hydrogen into the gas distribution networks.

Note the FFCRC are currently completing a scoping study with aims at identifying all industrial users of natural gas. The results of this project should be leveraged, where possible.

This recommendation will require involvement from industry groups and regulators.

5.4 COMPRESSED NATURAL GAS (CNG)

Table 34 provides a summary of the potential technical impacts of up to 10% hydrogen to CNG system; both stationary and mobile. Commercial and economic impacts were not considered as part of this study.

Table 34 Technical impacts of up to 10% hydrogen on CNG

Component	Function	Impact on component of up to 10% hydrogen	Technical risk
Refuelling and Storage			
Drier/Heater	Removes the moisture from the natural gas to ensure no damage to the downstream equipment.	For up to 10% hydrogen in natural gas blends is not likely to affect the existing component or change the risk profile.	No increased risk.
Filter/Coalescer	Removes solids and liquid contaminants from the natural gas to ensure no damage to the downstream equipment.	For up to 10% hydrogen in natural gas blends is not likely to affect the existing component or change the risk profile.	No increased risk.
Compressor	Compresses gas from the distribution network to 20 MPa.	<p>Relevant implications that may impact the performance and safety of this component:</p> <ul style="list-style-type: none"> Slightly increased permeation and leakage due to the smaller hydrogen molecule Increased risk of embrittlement. <p>Which, for up to 10% hydrogen in natural gas blends may lead to:</p> <ul style="list-style-type: none"> Increased leakage rates through seals, joints and fittings. Further investigation is required to confirm, however, it is likely that existing component will be suitable. Premature failure of steel components due to embrittlement. Further investigation is required to confirm, however it is likely that existing component will be suitable 	Before addition of hydrogen to a network, review of the compressor materials and suitability assessment, considering the compatibility for hydrogen, is recommended.
Storage	<p>Stores CNG at high pressures 20 MPa for when there is demand.</p> <p>Steels used include composites and high strength steels.</p>	<p>Relevant implications that may impact the performance and safety of this component:</p> <ul style="list-style-type: none"> Slightly increased permeation and leakage due to the smaller hydrogen molecule Increased risk of embrittlement. <p>Which, for up to 10% hydrogen in natural gas blends may lead to:</p> <ul style="list-style-type: none"> Increased leakage rates through seals, joints and fittings. Further investigation is required to confirm, however it is likely that 	<p>Type 1 and high strength steel vessel have a limit of 2% hydrogen.</p> <p>Before addition of hydrogen to a network, review of the storage materials and suitability assessment, considering the</p>

Component	Function	Impact on component of up to 10% hydrogen	Technical risk
		<p>existing component will be suitable.</p> <ul style="list-style-type: none"> Premature failure of steel components due to embrittlement. Further investigation is required to confirm, however, it is likely that existing component will be suitable <p>UNECE3 Regulation 110 for CNG vehicles specifies that the hydrogen content in CNG is limited to 2%, if the tank cylinders are manufactured from steel with an ultimate tensile strength exceeding 950 MPa.</p> <p>During the desktop review of CNG infrastructure, steel vessels currently in service were identified.</p>	<p>compatibility for hydrogen, is recommended.</p>
Dispenser	Transfers CNG from the buffer storage to the on-board vehicle fuel container.	<p>Relevant implications that may impact the performance and safety of this component:</p> <ul style="list-style-type: none"> Slightly increased permeation and leakage due to the smaller hydrogen molecule Increased risk of embrittlement. <p>Which, for up to 10% hydrogen in natural gas blends may lead to:</p> <ul style="list-style-type: none"> Increased leakage rates through seals, joints and fittings. Further investigation is required to confirm, however it is likely that existing component will be suitable. Premature failure of steel components due to embrittlement. Further investigation is required to confirm, however, it is likely that existing component will be suitable <p>It is expected that these dispensers found in operation will be likely stainless steel and suitable for addition of hydrogen. However, before the addition of any hydrogen that may be used in refuelling, a review of materials and suitable assessment is required.</p>	<p>Before addition of hydrogen to a network, review of the dispenser materials and suitability assessment, considering the compatibility for hydrogen, is recommended.</p>
Facility Piping	<p>Conveys gas within the refuelling facility.</p> <p>Gas inlet train designed to consumer piping</p>	<p>Relevant implications that may impact the performance and safety of this component:</p> <ul style="list-style-type: none"> Slightly increased permeation and leakage due to the smaller hydrogen molecule Increased risk of embrittlement. 	<p>Before addition of hydrogen to a network, review of the facility piping materials and suitability assessment,</p>

Component	Function	Impact on component of up to 10% hydrogen	Technical risk
	standards (AS/NZS 5601.1). Discharge piping is high-pressure piping (AS 4041).	Which, for up to 10% hydrogen in natural gas blends may lead to: <ul style="list-style-type: none"> Increased leakage rates through seals, joints and fittings. Further investigation is required to confirm, however it is likely that existing component will be suitable. Premature failure of steel components due to embrittlement. Further investigation is required to confirm, however it is likely that existing component will be suitable <p>It is expected that the facility piping found in operation will be likely stainless steel and suitable for addition of hydrogen. However, before the addition of any hydrogen that may be used in refuelling, a review of materials and suitable assessment is required.</p>	considering the compatibility for hydrogen, is recommended.
Workshop	The workshop / building where CNG vehicles are serviced.	For up to 10% hydrogen in natural gas blends is not likely to affect the existing component or change the risk profile.	No increased risk.
Vehicles and equipment			
Refuelling connection	Accepts CNG from the dispenser.	Relevant implications that may impact the performance and safety of this component: <ul style="list-style-type: none"> Slightly increased permeation and leakage due to the smaller hydrogen molecule Increased risk of embrittlement. <p>Which, for up to 10% hydrogen in natural gas blends may lead to:</p> <ul style="list-style-type: none"> Increased leakage rates through seals, joints and fittings. Further investigation is required to confirm, however, it is likely that existing component will be suitable. Premature failure of steel components due to embrittlement. Further investigation is required to confirm, however it is likely that existing component will be suitable <p>It is expected that the refuelling connection found in operation will be likely stainless steel and suitable for addition of hydrogen. However, before the addition of any hydrogen that may be used in refuelling, a review of materials and suitable assessment is required.</p>	It is likely that there will be no increased risk, but further investigation of the increased leakage rates and embrittlement is recommended.

Component	Function	Impact on component of up to 10% hydrogen	Technical risk
<p>Fuel container (Vehicle on-board storage)</p>	<p>Stores CNG at high pressure using cylindrical vessels Common storage type:</p> <ul style="list-style-type: none"> • Type 3 (Metal lined cylinder) • Type 4 (Composite cylinder) 	<p>Relevant implications that may impact the performance and safety of this component:</p> <ul style="list-style-type: none"> • Slightly increased permeation and leakage due to the smaller hydrogen molecule • Increased risk of embrittlement. <p>Which, for up to 10% hydrogen in natural gas blends may lead to:</p> <ul style="list-style-type: none"> • Increased leakage rates through seals, joints and fittings. Further investigation is required to confirm, however it is likely that existing component will be suitable. • Premature failure of steel components due to embrittlement. Further investigation is required to confirm, however, it is likely that existing component will be suitable <p>Fuel containers used in on-board storage are typically Type 3 and Type 4 cylinders, which are likely suitable for up to 10% hydrogen.</p> <p>It is expected that fuel container storage found in operation will be likely stainless steel or composite and suitable for addition of hydrogen. However, before the addition of any hydrogen that may be used in refuelling, a review of materials and suitable assessment is required.</p>	<p>It is likely that there will be no increased risk, but further investigation of the increased leakage rates and embrittlement is recommended.</p>
<p>Fuel container valve</p>	<p>Isolate the fuel container in the event of an emergency or maintenance.</p>	<p>Relevant implications that may impact the performance and safety of this component:</p> <ul style="list-style-type: none"> • Slightly increased permeation and leakage due to the smaller hydrogen molecule • Increased risk of embrittlement. <p>Which, for up to 10% hydrogen in natural gas blends may lead to:</p> <ul style="list-style-type: none"> • Increased leakage rates through seals, joints and fittings. Further investigation is required to confirm, however it is likely that existing component will be suitable. • Premature failure of steel components due to embrittlement. Further investigation is required to confirm, however it is likely that existing component will be 	<p>It is likely that there will be no increased risk, but further investigation of the increased leakage rates and embrittlement is recommended.</p>

Component	Function	Impact on component of up to 10% hydrogen	Technical risk
		<p>suitable</p> <p>It is expected that fuel container valve found in operation will be likely stainless steel and suitable for addition of hydrogen. However, before the addition of any hydrogen that may be used in refuelling, a review of materials and suitable assessment is required.</p>	
Pressure regulator	Reduces pressure from the fuel container to the required engine supply pressure.	Up to 10% hydrogen in natural gas blends is not likely to affect the existing component or change the risk profile.	No increased risk.
Manual valve	Isolates the fuel supply for maintenance or emergency	Up to 10% hydrogen in natural gas blends is not likely to affect the existing component or change the risk profile.	No increased risk.
Piping	<p>Piping and components upstream of the regulator are required follow the identified applicable standards.</p> <p>For low-pressure hose should comply with AS/NZS 1869.</p>	Up to 10% hydrogen in natural gas blends is not likely to affect the existing component or change the risk profile.	No increased risk.
Fuel Filter	Removes contaminants from the system.	Up to 10% hydrogen in natural gas blends is not likely to affect the existing component or change the risk profile.	No increased risk.
Engine	Combustion the natural gas to produce mechanical energy.	<p>Relevant implications that may impact the performance and safety of this component:⁹¹</p> <ul style="list-style-type: none"> • Slightly increased flame speed • Slightly increased flame temperature • Slightly decreased Wobbe Index • Slightly decreased Methane number. <p>Which, for up to 10% hydrogen in natural gas blends may lead to:</p> <ul style="list-style-type: none"> • Increased risk of light back in the engine although it is likely that existing component will be suitable. • Slightly increased risk of engine “knock” although it is likely that existing component will be 	<p>Likely to see a small impact to overall efficiency, potential increase in emission, increased risk of light back and engine “knock”</p> <p>However, likely manageable via tuning and minor modifications</p>

⁹¹ (Goyal & Sharma, 2014)

Component	Function	Impact on component of up to 10% hydrogen	Technical risk
		<p>suitable.</p> <ul style="list-style-type: none"> Possible higher NO_x but it is likely that existing component will be suitable; risk is expected to be negligible and manageable by tuning Possible slight increase in CO but slight decrease in CO₂. It is likely that existing component will be suitable; risk is expected to be negligible and manageable by tuning <p>Slight decrease overall burner efficiency. Risk is expected to be negligible and manageable by tuning</p> <p>Additionally, previous research suggests that up to 10% hydrogen in natural gas engines will still operate with no tunings or modification.⁹²</p>	

Each component was assigned a technical risk based on the following coding:

	There is no significant increase in risk for the component with addition of up to 10% hydrogen. In principle (subject to functional checks), the existing component could be used.
	Addition of up to 10% hydrogen requires further review of the impacts to this component, although it is likely that as is, the component will be suitable.
	The component technical not suitable or is unsafe with 10% hydrogen and will require further work.

5.4.1 Summary and recommendation

A desktop review of the technical suitability of CNG infrastructure for up to 10% hydrogen blended with natural gas was completed. It found that overall, the some of the steel equipment (storage, pipework, dispenser and compression may not be suitable for even small levels of hydrogen. Further investigation is required to provide the confidence to confirm that:

- There is no significant increase in materials related safety risks from leakage (through permeation and leakage through joints, fittings and connections) and HTHA in the general CNG infrastructure.
- There are no steel vessels in high-pressure CNG service that might receive blended gas with hydrogen of 2% or greater.

Further investigation of the technical impacts of hydrogen new and existing CNG appliances should be completed, in particular:

- Detailed review of the materials used in CNG infrastructure and suitability assessment for 10% hydrogen/natural gas blend, including identification of steel vessels for high-pressure steel storage (High strength Type 1 and Type 2 vessels).**

⁹² (Patil & Khanwalkar, 2009)

The results of this recommendation will further inform where there are additional safety, integrity and operational risks associated with the addition of up to 10% hydrogen into the gas distribution networks.

Note that these reviews are only required if there is CNG infrastructure located on a gas network where hydrogen is to be injected and should not prohibit injection where there is no CNG infrastructure.

This recommendation will require involvement from equipment manufacturers and regulators.

5.5 INSTALLATIONS

Classification of the types of installation as per AS/NZS 5601.1. Installations are either:

- Less than 200 kPa – Generally, this is domestic and light commercial applications such as restaurants.
- Over 200 kPa – Typically for larger users of natural gas supplied by the distribution network. These users will be connected to the trunk, primary, secondary and high-pressure mains.

The following section reviews the technical impact of up to 10% hydrogen on consumer installations (downstream of the consumer billing meter on the distribution network).

This study reviewed the impact of hydrogen on materials but did not assess the construction techniques and workmanship of the installations. It is likely that these will play a significant role in understanding the suitability of installations for up to 10% hydrogen and assessment of the impacts of workmanship of installations is a recommended area for further work.

5.5.1 Less than 200 kPa

For installations below 200 kPa the materials suitable and maximum operating pressures are prescribed in AS/NZS 5601 Table 4.1. Is therefore possible to review these materials for suitability of up to 10% hydrogen.

It is however important to note that while installations should be compliant with AS/NZS 5601.1, historically, non-compliances with this standard have been found.

Table 35 provides a summary of the components found in consumer appliance installations below 200 kPa.

Table 35 Components found in installations under 200 kPa

Type	Operating Pressure (kPa)	Typical materials of construction	Impact on component of up to 10% hydrogen	Technical risk
Regulator	<210	<u>Body:</u> <ul style="list-style-type: none"> • Steel • Cast Iron <u>Seals and O-rings:</u> <ul style="list-style-type: none"> • FMK (Viton N) • Nitrile Rubber (NBR, Buna N) • PTFE 	Relevant implications that may impact the performance and safety of this component: <ul style="list-style-type: none"> • Slightly increased permeation and leakage due to the smaller hydrogen molecule Which, for up to 10% hydrogen in natural gas blends may lead to: <ul style="list-style-type: none"> • Slightly increased leakage rate through joints, fittings and connections 	It is likely that there will be no increased risk but further testing of components for leakage is recommended
Manual shut-off valve	<210	<u>Body:</u> <ul style="list-style-type: none"> • Steel • Brass • Cast Iron <u>Seals and O-rings:</u> <ul style="list-style-type: none"> • FMK (Viton N) • Nitrile Rubber (NBR, Buna N) 	Due to the low operating pressures (200 kPa), it is likely that the existing components will be suitable; however further investigation is recommended Note: There is currently testing in progress by Evoenergy, ATCO and Mondo Labs.	

Type	Operating Pressure (kPa)	Typical materials of construction	Impact on component of up to 10% hydrogen	Technical risk
Consumer billing meter ⁹³	<210	<ul style="list-style-type: none"> PTFE 		
		<u>Body:</u> <ul style="list-style-type: none"> Steel Stainless Steel Cast Iron <u>Seals and O-rings:</u> <ul style="list-style-type: none"> FMK (Viton N) Nitrile Rubber (NBR, Buna N) PTFE 		
Welded	≤ 200	Steels listed in AS/NZS 5601.1:2013 Table 4.1.	No significant issues.	No increased risk
	≤ 200	Steels listed in AS/NZS 5601.1:2013 Table 4.1.	No significant issues.	No increased risk
Flanged	≤ 200	Carbon Steel Steel Alloy Cast Iron	Relevant implications that may impact the performance and safety of this component: <ul style="list-style-type: none"> Slightly increased permeation and leakage due to the smaller hydrogen molecule Which, for up to 10% hydrogen in natural gas blends may lead to: <ul style="list-style-type: none"> Slightly increased leakage rate through joints, fittings and connections Due to the low operating pressures (200 kPa), it is likely that the existing components will be suitable; however, further investigation is recommended	It is likely that there will be no increased risk but further testing of components for leakage is recommended
	<200	Copper alloy		
	<200	Copper alloy		
Threaded	<200	Stainless Steel (Grade 316)	Which, for up to 10% hydrogen in natural gas blends may lead to: <ul style="list-style-type: none"> Slightly increased leakage rate through joints, fittings and connections Due to the low operating pressures (200 kPa), it is likely that the existing components will be suitable; however, further investigation is recommended	It is likely that there will be no increased risk but further testing of components for leakage is recommended
	<100	Stainless Steel (Grade 316)		
Screwed	<7	Malleable Cast Iron	Due to the low operating pressures (200 kPa), it is likely that the existing components will be suitable; however, further investigation is recommended	It is likely that there will be no increased risk but further testing of components for leakage is recommended
	≤ 200	Copper alloy		
	≤ 200	Wrought steel		
Capillary Joints	<200	Stainless Steel (Grade 316)	Note: There is currently testing in progress by Evoenergy, ATCO and Mondo Labs. Leveraging off this work to inform future work would be beneficial	It is likely that there will be no increased risk but further testing of components for leakage is recommended
	<200	Copper Alloy		
Compression Fittings	<200	Stainless Steel (HNBR O-rings)	No significant issues	No increased risk

⁹³ The consumer billing meter, covered under AS 4645 (gas distribution network), was considered as part of this study.

Type	Operating Pressure (kPa)	Typical materials of construction	Impact on component of up to 10% hydrogen	Technical risk
		Copper (HNBR O-rings) Copper alloy (HNBR O-rings)		
	<200	Copper		
	<70	Polyethylene		
Solvent Cement	<70	PVC-H1 (Solvent Cement) PVC-U (Solvent Cement)	<p>Relevant implications that may impact the performance and safety of this component:</p> <ul style="list-style-type: none"> Slightly increased permeation and leakage due to the smaller hydrogen molecule <p>Which, for up to 10% hydrogen in natural gas blends may lead to:</p> <ul style="list-style-type: none"> Slightly increased leakage rate through joints, fittings and connections <p>Due to the low operating pressures (200 kPa), it is likely that the existing components will be suitable; however, further investigation will be recommended</p> <p>Note: There is currently testing in progress by Evoenergy</p>	It is likely that there will be no increased risk but further testing of components for leakage is recommended
Pipe	<210	All piping materials listed in AS/NZS 5601.1:2013 Table 4.1.	No significant issues	No increased risk
Hose	<210	All materials listed in AS/NZS 1869	<p>Relevant implications that may impact the performance and safety of this component:</p> <ul style="list-style-type: none"> Slightly increased permeation and leakage due to the smaller hydrogen molecule <p>Which, for up to 10% hydrogen in natural gas blends may lead to:</p> <ul style="list-style-type: none"> Slightly increased leakage rate through joints, fittings and connections <p>Due to the low operating pressures (200 kPa), it is likely that the existing components will be suitable; however, further investigation will be recommended</p>	It is likely that there will be no increased risk but further testing of components for leakage is recommended

Type	Operating Pressure (kPa)	Typical materials of construction	Impact on component of up to 10% hydrogen	Technical risk
			Note: There is currently testing in progress by Evoenergy, ATCO and Mondo Labs	

Each component was assigned a technical risk based on the following coding:

	There is no significant increase in risk for the component with addition of up to 10% hydrogen. In principle (subject to functional checks), the existing component could be used.
	There is likely no significant increase in risk for the component with addition of up to 10% hydrogen, but further investigation and testing is required to confirm.
	Addition of up to 10% hydrogen requires further review of the impacts to this component and it is likely that minor work will be required to ensure the component is suitable.
	The component technical not suitable or is unsafe with 10% hydrogen and will require further work.

5.5.2 Greater than 200 kPa

While permeation is understood, there is a lack of detail around leakage rates in equipment and joints, fittings and seals for up to 10% hydrogen.

Table 36 Risk of losses for up to 10% hydrogen in common materials through permeation ^{94 95 96}

Material	Type/Grade	Suitability for up to 10% hydrogen	Technical risk
Metallic			
Brass	All grades	No significant issues	No increased risk
Copper	All grades	No significant issues	No increased risk
Steel	All grades	Relevant implications that may impact the performance and safety of this component: <ul style="list-style-type: none"> Slightly increased permeation and leakage due to the smaller hydrogen molecule Increased risk of embrittlement Which, for up to 10% hydrogen in natural gas blends may lead to: <ul style="list-style-type: none"> Increased leakage rates through seals, joints and fittings. Further investigation is required to confirm, however it is likely that existing component will be suitable Premature failure of steel components due to embrittlement. Further investigation is required to confirm, however it is likely that existing component will be suitable. 	It is likely that there will be no increased risk, but further investigation of the increased leakage rates and embrittlement is recommended

⁹⁴ (Barthelemy, 2005)

⁹⁵ (Messaoudani, 2016)

⁹⁶ (Energy Pipelines Cooperative Research Centre, 2017)

Material	Type/Grade	Suitability for up to 10% hydrogen	Technical risk
		<p>In the low operating pressures installations (domestic and commercial), it is likely that the existing components will be suitable; however, further investigation is recommended.</p> <p>In high-pressure installations (commercial and industrial), it is likely that the existing components will be suitable; however, further investigation is recommended</p>	
Plastic	PE80, PE100	<p>Relevant implications that may impact the performance and safety of this component:</p> <ul style="list-style-type: none"> Slightly increased permeation and leakage due to the smaller hydrogen molecule <p>Which, for up to 10% hydrogen in natural gas blends may lead to:</p> <ul style="list-style-type: none"> Increased permeation rates through plastic piping systems. Further investigation is required to confirm, however it is likely that the existing component will be suitable <p>There is limited information on impacts to aged plastic piping systems although it is likely that they will be suitable. Further review of aged piping systems is recommended</p>	<p>Limited information onto aged plastic piping system although it is likely that they will be suitable. Further review of aged piping systems is recommended</p>
	PVC	<p>Relevant implications that may impact the performance and safety of this component:</p> <ul style="list-style-type: none"> Slightly increased permeation and leakage due to the smaller hydrogen molecule <p>Which, for up to 10% hydrogen in natural gas blends may lead to:</p> <ul style="list-style-type: none"> Increased permeation rates through plastic piping systems. Further investigation is required to confirm, however it is likely that existing component will be suitable <p>There is limited information on impacts to aged plastic piping systems although it is likely that they will be suitable. Further review of aged piping systems is recommended</p>	<p>Limited information onto aged plastic piping system although it is likely that they will be suitable. Further review of aged piping systems is recommended</p>
Non-metallic			
FMK	Viton N	<p>Relevant implications that may impact the performance and safety of this component:</p> <ul style="list-style-type: none"> Slightly increased permeation and leakage due to the smaller hydrogen molecule <p>Which, for up to 10% hydrogen in natural gas blends may lead to:</p>	<p>It is likely that there will be no increased risk but further testing of non-metallic materials for leakage is recommended</p>
Nitrile Rubber	NBR, Buna N	<ul style="list-style-type: none"> Slightly increased leakage rate through joints, fittings and connections this leakage rate is related to the operating pressure in the piping system. As the pressure increases the leakage rates increase. Although, it is expected that there will be no increased risk, further testing is recommended. 	
PTFE		Note: There is currently research and testing	

Material	Type/Grade	Suitability for up to 10% hydrogen	Technical risk
		underway by the FFCRC, National Renewable Energy Laboratory (NREL), Sandia Labs and HSE (UK). The results of this testing should be leveraged where possible	

Each component was assigned a technical risk based on the following coding:

	There is no significant increase in risk for the component with addition of up to 10% hydrogen. In principle (subject to functional checks), the existing component could be used.
	There is likely no significant increase in risk for the component with addition of up to 10% hydrogen, but further investigation and testing is required to confirm.
	Addition of up to 10% hydrogen requires further review of the impacts to this component and it is likely that minor work will be required to ensure the component is suitable.
	The component technical not suitable or is unsafe with 10% hydrogen and will require further work.

5.5.3 Summary and recommendation

A desktop review of the technical suitability of installation components for up to 10% hydrogen blended with natural gas was completed. It found that overall, the piping, components and fittings that make up the installations are likely to be suitable but further investigation is recommended in order to provide confidence in existing systems. Investigation should confirm that:

- There is no significant increase in materials related safety risks from leakage (through permeation and leakage through joints, fittings and connections). This applies for all pressures but becomes more evident as the pressures increase.
- There is no significant increase in embrittlement for steel piping systems, especially when the system is design to AS 4041 (above 200 kPa).
- There is no significant decrease in the durability and integrity of elastomers and polymers.
- There is no significant increase to safety related risk by the construction techniques and installation quality current used in installations.

Although likely that these components will be suitable for up to 10% hydrogen, further investigation of the technical impacts to new and existing installation components and methods should be completed, in particular:

- **Detailed review of the materials used in installation components and suitability assessment for 10% hydrogen/natural gas blend.**
- **Review of the impacts to safety of the construction techniques and installation quality currently used in consumer applications.**

The results of this recommendation will confirm there are no additional safety, integrity and operational risks associated with the addition of up to 10% hydrogen into the gas distribution networks.

This recommendation will require involvement from equipment manufacturers, industry and regulators.

Evoenergy, ATCO and Mondo Labs are currently testing common equipment, joints and fittings found in domestic and commercial applications. The results of these projects should be leveraged wherever possible to inform the scope of further work.

6 IMPACT TO AUSTRALIAN STANDARDS

This section reviews the impact of up to 10% hydrogen in a natural gas blend on the applicable Australian standards identified in this report. Whilst there are Australian standards potentially applicable to gas installations and downstream appliances, the standards identified as critical to gas appliances in the context of this report were:

1. AS 3814:2014 – Industrial and commercial gas-fired appliances
2. AS/NZS 5263.0:2017 – Gas appliances – General requirements
3. AS/NZS 5601.1:2013 – Gas installation – General installations
4. AS/NZS 4563:2004 – Commercial catering gas equipment
5. AS/NZS 1869:2012 – Hose and hose assemblies for liquefied petroleum gases (LPG), natural gas and town gas

The following standards were identified as being key relevant standards but are excluded from the scope of this report:

- AS 5092 – CNG Refuelling stations
- AS/NZS 5263 - Complete series
- AS 1375 – Industrial fuel-fired appliances⁹⁷

Additionally, it is recommended that the following standards should be reviewed:

- AS 4566 - Flue cowls - Gas appliances
- AS 4567 - Twin wall metal flues - Gas appliances
- AS 4617 - Manual shut-off gas valves
- AS 4618 - Gas appliance regulators
- AS 4620 - Thermoelectric flame safeguards
- AS 4622 - Electrical and electronic ignition devices for gas appliances
- AS 4623 - Jointing compounds and materials for use in gas pipe joints
- AS 4624 - Combination controls for gas
- AS 4625 - Electronic flame safeguards and flame detectors
- AS 4627 - Quick-connect devices for gas
- AS 4628 - Pressure and temperature limit devices for use with gas burners
- AS 4629 - Automatic shut off valves and vent valves
- AS 4630 - Leakage detection systems
- AS 4631 - Limited flexibility connectors for gas
- AS 4632 - Over-pressure and under-pressure cut off devices

These standards should be reviewed in time to understand the implications of addition of up to 10% hydrogen.

Table 37 provides a summary of the implications to the reviewed standards. Appendix 3 provides the detailed review of the Australian Standards.

Table 37 Summary of impact to standards

Standard	Interpretation for up to 10% hydrogen	Suitability for up to 10%
AS 3814	AS 3814 sets out the minimum requirements for the design, construction and safe operation of Type B appliances that use any gas (in combination with other fuels) to produce flame,	AS 3814 can be applied for hydrogen service.

⁹⁷ AS 1375 it specifies explosion relief and critical start time calculations which are used in AS 3814





Standard	Interpretation for up to 10% hydrogen	Suitability for up to 10%
	<p>heat, light, power or special atmospheres. A Type B appliance is an appliance with gas consumption in excess of 10MJ/h for which a certification scheme does not exist.⁹⁸</p> <p>The standard adopts a performance-based approach for gas-fired appliances. It is used by technical regulators to determine safe design of gas-fired appliances but acknowledges that the final decision in relation to compliance with this standard ultimately lies with the technical regulator.</p> <p>AS 3814 does not give a standard for gas quality. It states that gas appliances are to be designed for a particular quality of gas. Therefore, it is relevant for most types of combustible gas; additionally, the standard gives several references for varying gas compositions.</p> <p>Previously, the standard has been applied in Australia in pure hydrogen applications such as fuel cells.</p>	<p>During its next revision, the standard should be reviewed for the impact of up to 10% hydrogen and updated where required, although, there are minimal changes expected.</p>
AS/NZS 5263.0	<p>AS/NZS 5263.0 describes the minimum design requirements for gas appliances consuming up to 1000 MJ/h. Domestic and light commercial appliances are classified as Type A appliances. Type A appliance design, operation and safety is covered under the AS/NZS 5263 – Gas appliances series of standards, AS 4563 – Commercial catering gas equipment, and AS 3645:2017 - Essential Safety Requirements for Gas Equipment.</p> <p>The standard definition of natural gas does not include hydrogen in the gas composition (AS/NZS 5263.0 Section 1.1.1). The definition given in AS/NZS 5236 for natural gas is based upon the definition in AS 4564 that does not include hydrogen. Although these definitions do not strictly prohibit hydrogen, they were not written with consideration given to the impacts of hydrogen in the natural gas blend.</p> <p>The materials of construction of the appliance are not specifically listed in the standard but there are known material issues with hydrogen even at small concentrations. These impacts on materials may not impact appliance safety but may influence the reliability, integrity and durability of the appliance. Of particular interest are the increased risks of embrittlement, leakage, and high temperature hydrogen attack. for up to 10% hydrogen, given the relatively low operating pressures and low temperatures of Type A appliances these risks are expected to be negligible.</p> <p>The composition for test gas of natural gas (N_b test gas) are outlined in AS/NZS 5263.0 Table 3.1. The current N_b test gas includes 13% hydrogen (by volume) to provide a safety margin and simulate gas quality excursions in a gas network. If it is intended to have 10% hydrogen blended within the natural gas distribution network, there may be a requirement to increase the proportion of hydrogen in the test gas to maintain the same safety margin. Volumetrically this would require an increase in hydrogen content to approximately 21% hydrogen.</p>	<p>As written, the standard is currently not suitable for up to 10% hydrogen.</p> <p>Further investigation of the technical and safety impacts of hydrogen to appliances that comply with AS/NZS 5263.0 is required.</p> <p>Appliances that have been tested on natural gas will need to be reviewed for suitability of performance and safety when operating on a hydrogen/natural gas blend. Where there is a large number of appliances that need to be tested, a suitable strategy should be developed using a risk-based approach that builds on the research and testing currently being completed.</p>

⁹⁸ Type A appliances that are used for applications that it is not intended is considered a Type B appliance.

Standard	Interpretation for up to 10% hydrogen	Suitability for up to 10%
	<p>Throughout the standard, there are a number of prescriptive requirements e.g. diameter of flue connection. While from a high level these requirements seem likely suitable for up to 10% hydrogen, it is recommended they be reviewed and updated as necessary.</p> <p>Appliances that have been tested only on natural gas will need to be reviewed for suitability of performance and safety when operating on a 10% hydrogen/natural gas blend. As there are many appliances that need to be tested, a suitable strategy should be developed using a risk-based approach that builds on the research and testing currently being completed by the FFCRC.</p>	
AS/NZS 5601.1	<p>The AS/NZS 5601 Series specifies requirements and a means of compliance for the design, installation and commissioning of gas installations (including caravans and boats for non-propulsive purposes) that are associated with use or intended use of fuel gases such as natural gas, LP Gas, biogas or manufactured gas. Reviewed, as part of this study was AS/NZS 5601.1:2013 – Gas installation – General installations. Excluded from this study was AS/NZS 5601.2:2013 – Gas installation – LP Gas installations in caravans and boat for non-propulsive purposes.</p> <p>For application under 200 kPa the standard takes a prescriptive approach to compliance for materials, fittings and components, installation of consumer piping, installation of gas appliances and gives detailed design criteria that need to be complied with. Addition of up to 10% in the natural gas will affect the materials, joints, ventilations and construction techniques but application is likely to be suitable. A detailed review of AS/NZS 5601.1 section 2 is required, in particular Table 4.1, although it is likely that the current standards is suitable.</p> <p>For applications over 200 kPa the standard takes a performance-based approach. This method applies good engineering practice to design and installation. For these applications, the standard will generally be acceptable for new installations where the gas composition used for the design includes consideration for hydrogen or hydrogen blends. For existing installations, where hydrogen was not considered, installations a more detailed review will be necessary, although from it is likely that most equipment and components will be suitable for up to 10% hydrogen.</p> <p>Appendix 3C provides the detailed review of AS/NZS 5601.1.</p>	<p>For applications under 200 kPa a detailed review of the materials, construction methods and risk aspects will be required. It is likely that most current equipment will be suitable for addition of up to 10% hydrogen.</p> <p>For applications over 200 kPa the standard will generally be acceptable for up to 10% hydrogen for new installations as it is the installer's responsibility to ensure compatibility of the installation with the selected gas. For existing installations, a detailed review of the materials, construction methods and risk aspects will be required. It is likely that most current equipment will be suitable.</p>
AS/NZS 4563	<p>AS/NZS 4563 applies to various types of commercial catering equipment intended for use with natural gas, town gas, LPG and tempered LPG. The objective is to provide manufactures, designers, regulatory authorities, testing laboratories and similar organisations with uniform minimum requirements for the safety, performance and use of commercial catering equipment.</p> <p>Currently, hydrogen of up to 10%, is not considered in the listed gases. The definition for natural gas given in AS/NZS 4563 is a primarily methane-based gas. This is in-line with the definition given in other standards (AS/NZS 5263.0, AS/NZS 5601.1 and AS 4564).</p>	<p>As the standard is currently written, it is not suitable for up to 10% hydrogen.</p> <p>The test gases for natural gas ("N" and "S") are not likely suitable for up to 10% hydrogen.</p> <p>Further investigation of the technical and safety impacts of</p>

Standard	Interpretation for up to 10% hydrogen	Suitability for up to 10%
	<p>As with Type A appliances, the impacts of hydrogen were never considered during the preparation of the standard. However, it is likely that the materials risks and slight variation in combustion characteristics will have negligible impact on the operation, performance and safety of the appliances.</p> <p>The methods of test are likely suitable for up to 10% hydrogen. The methods outlined are not restricted to a particular gas and, with agreement on the test gas, could be applied for a hydrogen/natural gas blend.</p> <p>The test gases for natural gas (“N” and “S”) may not be suitable for up to 10% hydrogen. These are based upon nearly pure methane. The Wobbe Index for the “S” test gas is 45.7 MJ/m³ but for typical Australian natural gas compositions with 10% hydrogen the WI ranges between 43-49 MJ/m³. Further investigation is required to understand the impacts of lower WI on the performance, operation and safety of appliances designed to AS/NZS 4563.</p>	<p>hydrogen to appliances that comply with AS/NZS 4563 is required.</p> <p>There are currently several programmes underway in Australia that should be leveraged to inform further work.</p>
AS/NZS 1869	<p>AS/NZS 1869 specifies the requirements for hose and hose assemblies for the following services:</p> <ul style="list-style-type: none"> • Liquefied petroleum gas • Natural gas • Town gas manufactured from processing of oils • Tempered liquefied petroleum gas • Simulated natural gas in transport, automotive, industrial and domestic application <p>The standard applies for hoses up to 100mm inside diameter and 2.6 MPa maximum working pressure. Appendix 3E provides the detailed review of AS/NZS 5601.1.</p> <p>The objective of AS/NZS 1869 is to ensure performance, safety, durability and fitness for purpose of hose and hose assemblies in the gas industry.</p> <p>Currently the gases that are specifically covered under AS/NZS 1869 include natural gas but not a hydrogen/natural gas blend.</p> <p>The standard does not provide a materials selection list but rather requires the designer to select a material that is suitable for the gas service.</p> <p>For new hoses that are designed considering hydrogen as the gas, the standard is likely suitable. For existing hoses there needs to be further investigation into the materials compatibility and expected leakage rates when used for hydrogen and hydrogen blends. It is likely that most hoses will be suitable for up to 10% hydrogen blended with natural gas.</p>	<p>For new hoses that are designed considering hydrogen as the gas, the standard is likely suitable. For existing hoses there needs to be further investigation into the materials compatibility if hydrogen were to be introduced and expected leakage rates. It is likely that most hoses will be suitable for up to 10% hydrogen blended with natural gas.</p>

Each component was assigned a technical risk based on the following coding:

	The current standard can be applied for up to 10% hydrogen in natural gas.
	The current standard can be applied for up to 10% hydrogen in natural gas, however, to remove barriers further work is recommended.
	The current standard has significant barriers for up to 10% hydrogen in natural gas, however, to remove barriers further work will be required.
	The current standard has significant barriers for up to 10% hydrogen in natural gas and will require major revisions will be required.

6.1 SUMMARY AND RECOMMENDATION

A desktop review of the relevant technical safety standard gas appliances for up to 10% hydrogen blended with natural gas was completed. It found that overall, these relevant standards are likely to be suitable for application to blends of up to 10% hydrogen, but further investigation is recommended in order to provide confidence in the existing technical standards, specifically:

- There are no barriers in technical standards that were not reviewed as part of this study
- There are no barriers in technical standards that were identified by this study but not reviewed
- For the standards that were reviewed as part of this study, and minor barriers were identified, further investigation should be completed to ensure these standards are suitable

It is recommended that further investigation of technical suitability of and implications to the relevant Australian standards be completed, in particular:

- **Desktop review of the technical standards that were outside the scope of this report or identified during this report. These standards include:**
 - **AS 5092:2009 – CNG Refuelling stations**
 - **AS/NZS 5263 - complete series**
- **Detailed review of following standards is necessary further work to ensure the suitability for up to 10% hydrogen:**
 - **AS/NZS 5263.0**
 - **AS/NZS 4563**
 - **AS/NZS 5601.1**
 - **AS/NZS 1869**
- **Minor updates of the following standard during the next revision cycle to remove any barriers for hydrogen injection:**
 - **AS 3814**

The results of this recommendation will ensure that the relevant Australian standards are written with hydrogen considered as a component gas, and are applicable from a safety, integrity and operational risks perspective to the addition of up to 10% hydrogen into the gas distribution networks.

This recommendation will require involvement from equipment manufacturers, industry, standards committees and regulators

7 RECOMMENDATIONS AND AREAS OF INTEREST

Table 38 provides a summary of the recommendations identified throughout this study. The results of these recommendations will confirm there are no additional safety, integrity and operational risks associated with the addition of up to 10% hydrogen into the gas distribution networks.

Table 38 Recommendations

No.	Topic	Recommendation	Description
1	Review and update of standards	Review additional standards and update existing standards as identified by this study.	<p>Further investigation into technical suitability of, and implications to the relevant Australian standards be completed, in particular:</p> <ul style="list-style-type: none"> • Desktop review of the technical standards that were outside the scope of this report or identified during this report. These standards include: <ul style="list-style-type: none"> ○ AS 5092:2009 – CNG Refuelling stations ○ AS/NZS 5263 - complete series¹ ○ AS 1375 – Industrial fuel-fired appliances • Detailed review of following standards is necessary further work to ensure the suitability for up to 10% hydrogen: <ul style="list-style-type: none"> ○ AS/NZS 5263.0 ○ AS/NZS 4563 ○ AS/NZS 5601.1 ○ AS/NZS 1869 • Minor updates of the following standard during the next revision cycle to remove any barriers for hydrogen injection: <ul style="list-style-type: none"> ○ AS 3814
2	Type A performance and safety testing	Complete further assessment of flame stability in Type A, appliances	<p>Further investigation of the technical impacts new and existing Type A appliances should be completed, in particular, the impacts to flame stability, leakage rates through the gas valve and the consequences of increased moisture production from combustion.</p> <p>Although, it is likely that flame stability of Type A gas appliances will be suitable for up to 10%, further testing is required to provide satisfaction that this is the case.</p> <p>Note: There is currently testing in progress by Evoenergy, ATCO and Mondo Labs that should be leveraged where possible.</p>
6	Type B Audit	Complete a detailed review of type B appliances found in the distribution network.	<p>Investigation of the technical impacts to new and existing Type B appliances should be completed, in particular:</p> <ul style="list-style-type: none"> • Detailed review of the materials used in Type B appliances and suitability assessment for 10% hydrogen/natural gas blend. • Testing of Type B appliance burners to confirm that there are no increased safety impacts to flame stability. Testing of appliances with little or no tuning capabilities should be priority. • Detailed review and identification of appliances/processes that are

No.	Topic	Recommendation	Description
			<p>temperature sensitive and analysis of the impacts to these, in particular</p> <ul style="list-style-type: none"> ○ Glassmakers ○ Brick works <ul style="list-style-type: none"> • Review the impacts of increased NO_x to Type B appliances. • Review the impacts of increase water vapour to un-flued appliances.
5	Feedstock users Audit	Complete a detailed review of feedstock users using natural gas.	A scoping study to identify feedstock all users supplied from the distribution network.
6	CNG Audit	Investigation of CNG infrastructure before injection of hydrogen.	<p>Investigation of the technical impacts new and existing Type B appliances should be completed, in particular:</p> <ul style="list-style-type: none"> • Detailed review of the materials used in CNG infrastructure and their suitability assessment for 10% hydrogen/natural gas blend, including identification of steel vessels for high-pressure steel storage (Generally high strength Type 1 and Type 2 vessels).
7	Piping installations materials audit and suitability assessment	Complete a detailed review of materials found in end-user installations.	<p>Investigation of the technical impacts to new and existing installation components and methods should be completed, in particular:</p> <ul style="list-style-type: none"> • Detailed review of the materials used in installation components and suitability assessment for 10% hydrogen/natural gas blend. • Review of the impacts to safety of the construction techniques and installation quality currently used in consumer applications.

7.1 AREAS OF FURTHER INTEREST

The following areas of further interest were identified as part of this study:

- Impact of up to 10% hydrogen to LNG processing facilities.
- Impact of higher concentrations of hydrogen to appliances.
- Economic, commercial and regulatory reviews were excluded from the scope of this study. It is recommended that to fully assess the suitability of up to 10% hydrogen, these areas also be reviewed.

7.2 ACKNOWLEDGEMENTS

The National Hydrogen Strategy identified collaboration between industry and government as critical to the success of widespread take up of hydrogen. As such, a collaborative approach was taken to ensure the best outcomes for this project.

This report combines both government and industry experience and knowledge to provide a detailed overview of the technical and regulatory issues with hydrogen injection.

GPA Engineering acknowledges the valuable input by the many contributors to the development of this report, and for the contributions and support from the *Hydrogen in the gas networks* working group.

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7.2.2 Contributions

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APPENDIX 1 RESEARCH AND PROJECTS

Project	Type	Description
Type A Testing (FFCRC / The Australian Gas Association / University of Adelaide)	Testing	<p>This scope of this project is domestic appliances (Type A) and aims to testing the suitability of a suite of new gas appliances with up to 10% hydrogen. The objectives of this project are to:</p> <ul style="list-style-type: none"> Establish whether a wide range of appliances can be accredited for operation with NG with 10% H2 blended in. Testing of 17 new appliances is being completed at the AGA labs using existing test methods outline in AS/NZS 5263.0. Determine the maximum level of H2 that can be blended into natural gas before flashback or some other issue occurs in a range of Type A appliances. Identify the potential technical issues associated with converting to natural gas blends with higher levels of H2 than can be accommodated by current equipment. Develop a further project proposal with a full test matrix based on the literature review and initial tests that will address gaps in standard and industry needs. <p>On conclusion of the testing for up to 10% the appliances will be sent to the University of Adelaide for testing to identify the upper limits of hydrogen concentration.</p> <p>This project is ongoing and is expected to be completed by the end of 2019.</p>
Type B Scoping (FFCRC)	Literature Review / Scoping Study	<p>The scope of the project is to identify the largest existing natural gas users, their primary uses, current technical constraints and ballpark costs to convert to hydrogen blends (10 % or 20 %).</p> <p>The project objectives are to determine the gaps in knowledge regarding:</p> <ul style="list-style-type: none"> Range, tolerances and maximum levels of H2 that can be blended into natural gas for existing large gas users What is being done to identify technical issues for end-use equipment and on-site infrastructure with higher levels of H2 and 100% H2 Identify further research questions to address in FFCRC for high levels of hydrogen for large gas users <p>This project is ongoing and is expected to be completed by the end of 2019.</p>
Hydrogen test facility ⁹⁹ (Evoenergy / Canberra Institute of Technology)	Materials and equipment testing	<p>To gain a clear understanding of the impact of introducing hydrogen to existing infrastructure. The project includes a 200kW PEM electrolyser and testings facilities.</p> <ul style="list-style-type: none"> Testing existing Australian network components, construction and maintenance practices on 100% hydrogen application. Testing hydrogen as a broader energy storage source to support coupling the electricity network to the gas network. Appliance testing (e.g. testing hydrogen and mixed gases in existing appliances such as gas continuous hot water systems). Testing production of hydrogen from intermittent solar energy in sufficient quantities for small-scale domestic supply. <p>This project is ongoing and is expected to continue through to 2020.</p>

⁹⁹ (Hansen & Gaykema, 2019)

Project	Type	Description
		Preliminary results are due by the end of 2019.
Appraisal of domestic hydrogen appliances (UK) ¹⁰⁰	Literature Review	<p>This study explored the engineering challenges of developing domestic gas hobs, ovens, fires and boilers that can run on 100% hydrogen in the UK.</p> <p>This project had two key steps. Firstly, it has investigated the impact, at a component level, of running appliances designed for natural gas on hydrogen and has identified the key technical issues and the components that will need to be redesigned. Secondly, it has considered the following three options for hydrogen appliances, and in each case evaluated the performance, practical considerations and developmental timescales and costs:</p> <ul style="list-style-type: none"> • New appliances developed specifically to run on hydrogen; • Adaptation of existing natural gas appliances in-situ to run on hydrogen; • New dual-fuel appliances that can switch from natural gas to hydrogen. <p>The study involved a systematic review of the available literature as well as detailed industry engagement involving 1-2-1 conversations and a discussion workshop. The industry engagement included appliance and component manufacturers, gas testing bodies, maintenance and servicing contract companies, trade associations and consultancies.</p>
HyDeploy ¹⁰¹	Materials and equipment testing	<p>The HyDeploy project has undertaken a programme of work to assess the effect of hydrogen addition on the safety and performance of gas appliances and installations. A representative set of eight appliances have been assessed in laboratory experiments with a range of test gases that explored high and low Wobbe Number and hydrogen concentrations up to 28.4 % mol/mol. Tests have demonstrated that the addition of hydrogen does not affect the key hazard areas of CO production, light back, flame out or the operation of flame failure devices. It has identified that for some designs of gas fire appliances the operation of the oxygen depletion sensors may be affected by the addition of hydrogen and further studies in this area are planned. A laboratory-based study was supported by an onsite testing programme where 133 installations were assessed for gas tightness, appliance combustion safety and operation against normal line natural gas, G20 reference gas and two hydrogen blended gases. Where installations were gas tight for natural gas, analysis showed that no additional leakage occurred with hydrogen-blended gases. There were also no issues identified with the combustion performance of appliances and onsite results were in line with those obtained in the laboratory-testing programme.</p>
Hy4Heat ¹⁰²	(WP6) Industrial Appliance review	<p>Hy4Heat is a programme commissioned by the Department for Business, Energy & Industrial Strategy (BEIS), to explore whether replacing natural gas with hydrogen for heating and cooking is feasible and could be part of a plausible potential pathway to help meet heat decarbonisation targets.</p> <p>This programme will seek to provide the technical, performance, usability and safety evidence to demonstrate whether hydrogen can be used for heat and cooking.</p> <p>BEIS is working with industry and other stakeholders to build understanding of the different approaches, to prepare for decisions in</p>

¹⁰⁰ (Frazer-Nash Consultancy, 2018)

¹⁰¹ (Hawksworth & McCluskey, 2019)

¹⁰² (Department for Business, Energy & Industrial Strategy, 2019)

Project	Type	Description
ATCO	Materials and equipment testing	<p>the first half of the next decade about the long-term future of heat.</p> <p>ATCO's hub will investigate the potential role of hydrogen in the future energy mix, with operations to include testing different combinations of energy blends and integrating natural gas, as well as examining the role hydrogen could play in hybrid micro grids and as a future balancing fuel to support WA's electricity grid.</p> <p>The facility includes an PEM electrolyser and test facility for testing the performance and safety of a range of appliances, components and equipment.</p> <p>The Jandakot facility will test blends of up to 10% hydrogen in domestic and commercial gas appliances, including:</p> <ul style="list-style-type: none"> • Hot water boiler • Gas powered air conditioning • BBQ • Cooktop • Commercial kitchen. <p>This test program has commenced and preliminary results are expected by early 2020.</p> <p>Additionally the site will be testing a 100% hydrogen domestic cooktop, fuel cell and BBQ. These will be tested for performance, safety and regulatory compliance.</p>

APPENDIX 2 GAS QUALITY CALCULATION

APPENDIX 3 AUSTRALIAN STANDARDS REVIEW

Appendix 3A AS 3814 – Industrial and commercial gas-fired appliances

Standard	AS 3814:2018	Standards Committee	AG-011 (Industrial and Commercial Gas-Fired Appliances)
Latest Revision	2018	Next Planned revision	No revision planned
Scope			
<p>AS 3814 sets out the minimum requirements for the design, construction and safe operation of Type B appliances that use any gas (in combination with other fuels) to produce flame, heat, light, power or special atmospheres.</p> <p>A Type B appliance is an appliance with gas consumption in excess of 10MJ/h for which a certification scheme does not exist. Type A appliances that are used for applications that it is not intended is considered a Type B appliance.</p> <p>There are several appliances types that are excluded from AS 3814 including:</p> <ul style="list-style-type: none"> • Manually operated Bunsen type burners • Simple atmospheric burners and simple forced draught burners • Petroleum, petrochemical and natural gas flares • Petroleum and natural gas pressure relieving systems • Engines other than stationary • Refrigeration systems that utilise gas as a refrigerant • Vaporising liquid fuel burners (refer AS 1375) <p>For the purpose of this standard gas is defined as:</p> <p><i>“A combustible fuel that is a gas at normal temperature and pressure that could be any one of, but is not limited to, the following:</i></p> <p>(a) <i>Natural gas (NG)</i> (b) <i>Simulated natural gas (SNG)</i> (c) <i>Tempered liquefied petroleum gas (TLPG)</i> (d) <i>liquefied petroleum gas (LPG)</i> (e) <i>biogas”</i></p>			
Objective			
<p>The objective of this standard is to provide uniform minimum requirements for the safe operation of gas-fired industrial appliances for commercial applications.</p> <p>Compliance with AS 3814 is mandated by the technical regulator in many jurisdictions in Australia.</p> <p>Additional to the requirements outline in AS 3814 the overall safety of the process shall be designed in accordance with AS 1375 – <i>Industrial fuel-fired appliances</i>. A risk assessment is required on the appliance and associated installation to ensure it complies with the standard.</p> <p>The standard does not prescribe a fuel quality but advises that the appliances (and associated components) shall be designed to:</p> <p><i>“ensure that the fuel gas quality and composition does not adversely affect the integrity and safe operation and combustion process of the appliance”</i></p>			
Referenced Australian Standards			
<p>AS 1271, AS 1357, AS 1357.1, AS 1357.2, AS 1668, AS 1668.2, AS 2593, AS2885, AS2885.1, AS 4041, AS 4564, AS 4617, AS4618, AS 4620, AS 4624, AS 4625, AS 4629, AS 4630, AS 4631, AS 4670, AS 4732, AS 4983, AS 61508, AS61508.1, AS61508.2, AS 61508.5, AS 62061, AS/NZS 1425, AS/NZS 1596, AS/NZS 1869, AS/NZS 3000, AS/NZS 4024, AS/NZS 4024.1401, AS/NZS 4114, AS/NZS 5601, AS/NZS 5601.1, AS/NZS 60079, AS/NZS 60079.10.1</p>			
Legislation referencing this standard			

Standard	AS 3814:2018	Standards Committee	AG-011 (Industrial and Commercial Gas-Fired Appliances)		
<ul style="list-style-type: none"> • Gas (Safety) Regulations 2014 No. 62 (TAS) • Gas (Safety) Regulations 2002 No. 78 (TAS) • Gas Regulations 2012 No. 200 (SA) • Gas Regulations 1997 No. 162 (SA) • Gas Safety (Gas Installations) Regulations 2008 No. 165 (VIC) • Gas Safety Regulations 2001 No. 18 ACT • Gas Standards (Gasfitting and Consumer Gas Installations) 2010 (WA) • Gas Standards (Gasfitting and Consumer Gas Installations) 1999 (WA) • Occupational Licensing (Gas-fitting Work) Regulations 2010 No. 129 (TAS) • Petroleum and Gas (Royalty) Regulations 2004 No. 309 (QLD) • Plumbing Regulations 2008 No. 136 (VIC) 					
Work being completed by the standards committee with respect to hydrogen					
No work completed at this stage.					
Methodology					
<p>AS 3814 adopts a performance-based approach for gas-fired appliances. The standard is used by technical regulators to determine safe design of gas-fired appliances but acknowledges that the final decision in relation to compliance with this standard ultimately lies with the technical regulator.</p> <p>The standard is not prescriptive but sets out a baseline of requirements for the design and construction of large gas-fired appliances.</p> <p>For any modification to the appliance, whether it be to the appliance itself, the operating conditions or anything else integrally linked to the appliance, it is the owner/operator's responsibility to notify the regulator and to ensure that these changes are still acceptable under AS 3814.</p> <p>While the definition of "gas" in the standard does not include hydrogen, this does not specifically exclude hydrogen. Hydrogen was never considered during the preparation of the standard, but it is understood that the standard can be applied for this application.</p>					
General technical impacts of hydrogen					
<p>The following parameters and characteristic have been identified as impacted by the addition of up to 10% hydrogen in a typical natural gas blend. The extent of the impacts is outlined in the "summary of technical implications" section of the report.</p> <p>"x" = specifically reference in AS 3814.</p>					
Thermal Radiation		Wobbe Index	x	Stratification	
Light back	x	Methane Number		Air dilution ratios	
Flame speed	x	Sooting Index		Measurement of gas	
Yellow tipping		Flammability limit	x	Gas detection	
Moisture	x	Higher heating value		Hazardous Area	
NO _x emissions	x	Flame emissivity	x	Worker Safety	
Flame Temperature	x	JT cooling effect		Gas build-up in buildings	
Stoichiometric Composition	x	Minimum Ignition Energy		Auto ignition temperature	

Standard	AS 3814:2018	Standards Committee	AG-011 (Industrial and Commercial Gas-Fired Appliances)
			Radiation and dispersion
Example specific considerations for hydrogen			
<p><u>Unusual installations</u></p> <p>(Section 1.2.5) Installations that are not covered in detail in the standard may be reviewed in conjunction with the technical regulator. This could be applicable to hydrogen applications initially, before more widespread introduction of hydrogen into gas-fired appliances.</p> <p><u>Modification or relocation of an appliance</u></p> <p>(Section 1.2.6) Where an appliance is modified or relocated, it should be upgraded to meet the requirements of AS 3814. If the gas composition is changed then the owner will be responsible for ensuring the existing equipment complies with AS 3814.</p> <p><u>Materials</u></p> <p>Section 2.8.3 identifies that materials,</p> <p style="padding-left: 40px;"><i>“shall be suitable for use with the gas for which the equipment has been design.”</i></p> <p>Addition of hydrogen to the fuel gas composition may result in embrittlement of carbon steels. For up to 10% hydrogen the effects of hydrogen embrittlement should be negligible, however confirmation on a case-by-case basis is required.</p> <p>Additionally, all plastics, rubbers and other materials should be reviewed for suitability of use with a blend that includes hydrogen.</p> <p><u>Gas Filters</u></p> <p>Section 2.14.1 (d) of the standard states that gas filters should be fitted to appliances that are supplied with gas that is not conforming to AS 4564. Whilst a blend of up to 10% hydrogen in natural gas is likely to comply with AS 4564, in cases where it doesn't, the requirement to fit gas filters should be reviewed. For the case of up to 10% hydrogen where the expected quality of the hydrogen/natural gas supply will be better than the quality set-out in AS 4564 no additional filter will be required.</p> <p><u>Maximum temperature of mixtures</u></p> <p>Section 2.18.5.2 gives the typical values for auto-ignition temperature (AIT) of gases. This does not include a hydrogen or hydrogen blended-natural gas and should be updated.</p> <p><u>Burner start gas rate</u></p> <p>Section 3.2.3 Outlines the requirements for the burner start gas rate by several methods. As per the technical review completed, addition of up to 10% hydrogen does affect the LEL by approximately 10%. Each Type B appliance would need to be reviewed to see if the new value of LEL affects the minimum requirements set out in table 3.1 and 3.2.</p> <p><u>Markings to be displayed (4.1.1)</u></p> <p>The gas type is required to be clearly marked on each appliance. Any change in composition beyond what is already marked on the appliance should be clearly labelled.</p>			
Suitability of the standard for up to 10% hydrogen			
<p><u>New Appliances</u></p> <p>AS 3814 does not give a standard for gas quality. It states that gas appliances shall be designed for a particular quality of gas. It is relevant for most type's combustible gas and references a number of gas types.</p> <p>Additionally, the standard has previously been applied, in Australia, in pure hydrogen applications such as fuel cells.</p> <p><u>Existing Appliances</u></p>			

Standard	AS 3814:2018	Standards Committee	AG-011 (Industrial and Commercial Gas-Fired Appliances)
<p>Although the standard allows hydrogen, any change of gas composition, from the original design, would require a review and re-certification. This would be done on a case-by-case basis unless a strategy for all appliances on a particular network could be developed.</p>			
<p style="text-align: center;">Research currently being completed with respect to hydrogen that will support this standard</p>			
<p><u>FFCRC Type B Project</u></p> <p>The FFCRC are currently completing a scoping study which will identify the impacts of hydrogen of varying concentrations to Type B appliance users and natural gas process users. The scoping study is expected to be completed by December 2019 and will identify further work and practical testing required.</p>			

Appendix 3B AS/NZS 5263.0 – Gas appliances – General Requirements

Standard	AS/NZS 5263.0	Standards Committee	AG-001 – Gas Appliances
Latest Revision	2017	Next Planned revision	Early 2021
Scope			
<p>AS/NZS 5263.0 specifies general requirements and test methods for appliances and equipment which use:</p> <ul style="list-style-type: none"> • natural gas (as described by AS 4564), • town gas, • liquefied petroleum gas (LP Gas, as described by AS 4670) and • tempered liquefied petroleum gas (TLP), <p>as a fuel which are intended for domestic, commercial or light industrial use to an energy input limit of 1000 MJ/h or any lower limit specified in the appliance-specific part of the AS 5263 series of Standards i.e. part 1 - AS/NZS5263.1.1 Domestic Gas Cooking</p> <p>AS/NZS 5263.0 defines “gas” as:</p> <p style="padding-left: 40px;"><i>“A combustible fuel gas that may be one of the following:</i></p> <ol style="list-style-type: none"> 1. <i>Natural Gas (NG) – A hydrocarbon gas primarily consisting of methane.</i> 2. <i>Simulated natural gas (SNG) - A gas in air mixture comprising approximately 55% commercial propane and 45% air.</i> 3. <i>Town Gas (TG) - A gas manufactured from coal or petroleum feedstock’s, usually contains high levels of carbon monoxide.</i> 4. <i>Tempered liquefied petroleum gas (TLP) - A gas in air mixture comprising approximately 27% commercial propane and 73% air.</i> 5. <i>Liquefied petroleum gas (LP Gas) - A gas composed predominantly of any of the following hydrocarbons, or any combination of them in the vapour phase; propane, propene (propylene), butane, butene (butylene) and pentane.”</i> <p>The definition for natural gas can additionally be further defined in AS 4564 or, in some cases, state regulation.</p>			
Objective			
<p>The objective of AS/NZS 5263.0 is to provide manufacturers, designers, regulatory authorities, testing laboratories and similar organizations with uniform minimum requirements for the safety, performance and use of gas consumer appliances.</p>			
Referenced Australian Standards			
<p>AS 1375, AS 1722, AS 1722.2, AS 27000, AS 3645, AS 3688, AS4564, AS 4567, AS 4617, AS 4620, AS 4625, AS 4627, AS4629, AS 4631, AS 4670, AS 5263*, AS/NZS 1869, AS/NZS 5601*</p> <p>*denotes series of standards</p>			
Referenced in legislation			
<p>It is embedded in the Energy Products (Safety and Efficiency) Proclamation 2012. Section 6— Certification—gas products For the purposes of section 6(2) of the Act— (a) subsection (2) applies to each class of gas product that is listed in Appendix A of AS 3645—2010; This standard has since been updated in 2017 will again once Part 0 is updated. All appliance references are in this Proclamation.</p>			
History of the standard			
<p>This Standard was prepared by the members of Standards Australia Committee AG-001, the first release was 2013. This standard was further revised by the Joint Standards Australia/Standards New Zealand Committee AG-001 and published in 2017.</p> <p>AS/NZS 5263.0, together with other Standards in the AS 5263 series specific to appliance types</p>			

Standard	AS/NZS 5263.0	Standards Committee	AG-001 – Gas Appliances		
<p>(Part 1.X), constitute a means of compliance with AS 3645, Essential requirements for gas equipment, for each appliance type.</p> <p>The new standard series was intended to supersede all previous Type A standards.</p>					
Work being completed by the standards committee with respect to hydrogen					
<p>Currently the impact of hydrogen is being considered and any updates will be made in-conjunction with the assistance of ME093 as it mirrors the activities of ISO/TC197.</p>					
Methodology					
<p>Section 2 of the standard outlines the requirements necessary to design, construct and present a gas appliance that complies with AS 3645.</p> <p>Section 3 of the standard outlines the methodology for preliminary tests of line gases.</p> <p>Section 4 of the standard outlines the methodology for completing the limit gas tests. It gives specific instruction on how to test with the limit gas as outlined in Table 3.1. Appliances must comply with the requirements of this section when supplied with the limit gases under the conditions outlined.</p> <p>Section 5 of the standard provides the performance specifications that the appliance is required to meet.</p>					
General technical impacts of hydrogen					
<p>The parameters and characteristics listed below have been identified as impacted by the addition of up to 10% hydrogen in a typical natural gas blend. The extent of the impacts is outlined in the “summary of technical implications” section of the report.</p> <p>“x” = specifically reference in AS/NZS 5263.1.</p>					
Thermal Radiation		Wobbe Index	x	Stratification	
Light back	x ¹	Methane Number		Air dilution ratios	
Flame speed		Sooting Index		Measurement of gas	
Yellow tipping	x ¹	Flammability limit		Gas detection	
Moisture	x	Higher heating value	x	Hazardous Area	
NO _x emissions	x	Flame emissivity		Worker Safety	
Flame Temperature		JT cooling effect		Gas build-up in buildings	
Stoichiometric Composition		Minimum Ignition Energy		Auto ignition temperature	x
Flame lifting	x ¹			Radiation and dispersion	
Notes					
<p>¹ Yellow tipping, Light back and Flame lift are considered flame abnormalities (section 1.3.32)</p>					
Examples specific considerations for hydrogen					
Screwed Connections (2.5.4)					
<p>The standard allows for screwed connections. Testing of screwed connections, even at low pressure is required because of current lack of leak likelihood data.</p>					
Provision of pressure regulator (2.8.2)					

Standard	AS/NZS 5263.0	Standards Committee	AG-001 – Gas Appliances
<p>The standard does not currently allow for a hydrogen blend in the selection of regulator pressure. With the addition of hydrogen, the pressure is required to increase to get the same energy throughput which may lead to a constraint through the regulator although, for up to 10% Hydrogen in NG it is likely the regulators will still be acceptable.</p> <p><u>Gas Type Colour Codes (Table 2.14.9)</u></p> <p>Hydrogen is not represented on the colour codes although it would be assumed that it would still fall-under the NG gas type. Eventually there may be a requirement to differentiate but initially for up to 10% the existing system will be suitable.</p>			
Suitability of the standard for up to 10% hydrogen			
<p>The standard definition of natural gas does not allow for hydrogen in the gas composition (Section 1.1.1). This is because the definition given for natural gas is based upon the definition given in AS 4564 which does not currently specifically prohibit hydrogen.</p> <p>The materials of construction of the appliance are not specifically listed in the standard but there are known material issues with hydrogen even at small concentrations. These impacts on materials may not be to safety but may influence the reliability, integrity and durability of the appliance.</p> <p>The test gas for NG is outlined in table 3.1 This is typically the N_b test gas. The current N_b test gas has 13% hydrogen which is to provide a safety margin and simulate as quality excursions in a gas network. If it is intended to have 10% hydrogen with the gas network, there may be a requirement to increase the proportion of hydrogen in the test gas to maintain the same safety margin to the gas characteristics. This would be to approximately 21 % hydrogen.</p> <p>Throughout the standard, there are a number of prescriptive requirements given e.g. diameter of flue connection. While these appear reasonable for up to 10% hydrogen, it is recommended these be reviewed and updated, if required.</p> <p>Appliances that have been tested only on natural gas will need to be reviewed for suitability of performance and safety when operating on a hydrogen/natural gas blend. Where there is a large number of appliances that need to be tested, a suitable strategy will need to be developed using a risk-based approach that builds on the research currently being completed by the FFCRC.</p>			
Research currently being completed with respect to hydrogen that will support this standard			
<p><u>FFCRC Type A testing</u></p> <p>The testing for Type A appliances will provide an understanding the impacts of up to 10% hydrogen with the appliances tested. This testing with 10% hydrogen in NG is being completed on 17 new Type A appliances by an accredited testing laboratory using the same testing procedure as for a regular natural gas unit, except for the gas blend.</p> <p><u>International testing</u></p> <p>There are numerous appliance research testing projects underway internationally. Although, there appears to be promising results for concentrations of hydrogen up to 30%, different supply pressures and testing requirements in Australia means the results from these studies cannot be fully relied upon. However, International testing could provide guidance on the decisions to test for different appliances in Australia.</p>			
Recommendation			
<p>It is recommended that AS/NZS 5263 be updated be completed to reduce the barriers to use of hydrogen in gas appliances covered by this standard. The standard has been prepared without hydrogen in mind but as the standard is currently written, it does not explicitly prohibit the use of hydrogen.</p>			

Standard	AS/NZS 5263.0	Standards Committee	AG-001 – Gas Appliances
<p>The update of the standard should be completed during the next revision which is planned for early 2021. This recommendation should be championed by the AG-001 standards committee. Further testing of legacy appliances for flame stability and materials durability will be required to help guide the standards committee.</p>			

Appendix 3C AS/NZS 5601.1 – Gas Installations – General Installations

Standard	AS/NZS 5601.1	Standards Committee	AG-006 – Gas Installations
Latest Revision	2013	Next Planned revision	No revision planned
Scope			
<p>AS/NZS 5601.1 contains the mandatory requirements and means of compliance for the design, installation and commissioning of gas installations that are associated with the use or intended use of fuel gases such as natural gas, LP Gas, or biogas.</p> <p style="padding-left: 40px;"><i>“For Australia, these requirements cover gas installations downstream of the outlet of—</i></p> <ul style="list-style-type: none"> <i>a) the consumer billing meter installation;</i> <i>b) the first regulator on a fixed gas installation where an LP Gas tank or cylinder(s) is installed on site; or</i> <i>c) the first regulator on site (if no meter is installed) where LP Gas is reticulated from offsite storage.”</i> <p>Where “Installation” is:</p> <p style="padding-left: 40px;"><i>“deemed to include the pipework, appliances, flues, air ducts, ventilation and other ancillary items.”</i></p>			
Objective			
The objective of this Standard is to provide essential requirements and deemed-to-comply solutions, and to promote uniform standards of gas installation.			
Referenced Australian Standards			
AS 1074, AS 1210, AS 1345, AS 1357, AS 1397, AS 1432, AS 1464, AS 1530, AS 1572, AS2129, AS 2738, AS 2944, AS 3688, AS 3814, AS 4041, AS 4176, AS 4553, AS 4566, AS 4567, AS 4617, AS 4623, AS 4627, AS 4629, AS 4631, AS 5200, AS/NZS 1167, AS/NZS 1260, AS/NZS 1477, AS/NZS 1518, AS/NZS 1530, AS/NZS 1596, AS/NZS 1734 AS/NZS 1869, AS/NZS 2208, AS/NZS 2492, AS/NZS 2537, AS/NZS 2648, AS/NZS 2918, AS/NZS 4129, AS/NZS 4130, AS/NZS 4645, AS/NZS 60079			
Legislation referencing this standard			
<ul style="list-style-type: none"> • Constructoin Occupations Regulatrion 2004 No. 36 (ACT) • Gas (Safety) Regulation 2014 No. 62 (TAS) • Gas and Electricity (Consumer Safety) Regulatrion 2018 (NSW) • Gas Regulations 2012 (SA) • Gas Safety (Gas installation) Regulations 2018 (VIC) • Gas Safety (Gas installation) Regulations 2008 (VIC) • Petroleum and Gas (Royalty) Regulation 2004 (QLD) • Plumbing Regulations 2018 (VIC) 			
History of the standard			
<p>The second edition of AS/NZS 5601.1 was prepared by Joint Technical Committee (AG-006 - Gas Installations) and approved in 2013. This edition had minor updates from the previous.</p> <p>Before this, the standard existed as AS 5601/ AG 601 – 2000 in Australia and NZS 5261:1996 in New Zealand. These standards were combined and the first edition of AS/NZS 5601.1 was released in 2010.</p> <p>For the first edition, all Australian and New Zealand Technical Regulators agree that AS/NZS 5601.1 should provide for particular appliances and components to be certified. It was also agreed that AS/NZS 5601.1 include a statement that this requirement would not apply retrospectively.</p>			

Standard	AS/NZS 5601.1	Standards Committee	AG-006 – Gas Installations		
Work being completed by the standards committee with respect to hydrogen					
No work completed at this stage.					
Methodology					
<p>This standard has been adopted by regulatory bodies (Technical regulators) in some states (and territories) of Australia. The Standard accommodates some variation of requirements among the regulatory jurisdictions. Appendix N sets out the detail of these variations. Where adopted by regulation the requirements set out in this standard become mandatory and shall be adhered to for gas installations.</p> <p>The standard has a mixture of performance based and prescriptive elements.</p> <p>The user of AS/NZS 5601.1 is expected to be familiar with the properties and characteristics of those fuel gases and the principles of combustion, ventilation and fluing applicable to the safe installation and operation of gas appliances.</p> <p><u>For pressure less than 200 kPa</u></p> <p>Sections 3 to 6 give takes a prescriptive approach. These sections provide more detailed information as a “means of compliance” with installations designed to operate with a gas supply pressure not exceeding 200 kPa.</p> <p><u>For pressure exceeding 200 kPa</u></p> <p>Section 2 of AS/NZS 5601.1 takes a performance and risk-based approach. Section 2 details the various aspects of a gas installation that contribute to its safety, stating performance criteria for compliance with legislative requirements for safety of gas installations. This includes applications where the operating pressure exceeds 200 kPa</p>					
General technical impacts of hydrogen					
<p>The parameters and characteristics listed below have been identified as impacted by the addition of up to 10% hydrogen in a typical natural gas blend. The extent of the impacts is outlined in the “summary of technical implications” section of the report.</p> <p>“x” = specifically reference in AS/NZS 5601.1.</p>					
Thermal Radiation		Wobbe Index	x	Stratification	
Light back		Methane Number		Air dilution ratios	x
Flame speed		Sooting Index		Measurement of gas	x
Yellow tipping		Flammability limit	x	Gas detection	x
Moisture	x	Higher heating value		Hazardous Area	x
NO _x emissions		Flame emissivity		Worker Safety	
Flame Temperature		JT cooling effect		Gas build-up in buildings	x
Stoichiometric Composition		Minimum Ignition Energy		Auto ignition temperature	
Flame lifting				Radiation and dispersion	x

Standard	AS/NZS 5601.1	Standards Committee	AG-006 – Gas Installations
Examples of specific considerations for hydrogen			
<p><u>Interpretation (Section 1.7)</u></p> <p>This section outlines the average Wobbe Index for practically available gases. The range given for natural gas is most likely suitable for up to 10% hydrogen in natural gas (based on a typical Australian natural gas composition).</p> <p><u>Explosive Limit (Section 1.8.32)</u></p> <p>This section outlines the Upper explosive limit (UEL) and Lower explosive limit (LEL) for Natural Gas, Synthetic Natural Gas and LP gas. The limits given for natural gas are not correct for a natural gas blend with up to 10% hydrogen.</p> <p><u>Gas (1.8.45)</u></p> <p>The definition for natural gas, that are given, would not apply for a hydrogen/natural gas mixture.</p> <p><u>Consumer Piping Materials (Table 4.1)</u></p> <p>This table outlines the materials that are suitability for operating pressures under 200 kPa but does not specify the suitability for gas composition. It is the installers responsibility to confirm the compatibility of material with the gas composition (Section 4.1.1).</p> <p><u>Minimum Pressure at appliance inlet (Table 5.1)</u></p> <p>This table outlines the minimum pressure for gases at the appliance inlet and does not consider hydrogen in natural gas mixture. No methodology for calculation of the minimum pressure is given. Due to the reduction in energy throughput, the minimum pressure would not be accurate for up to 10% hydrogen in natural gas mixture. However, it is likely that the minimum pressure would still be suitable. Further confirmation is required.</p> <p><u>Venting (5.11.5)</u></p> <p>This section outlines the minimum requirements for venting. Although it is expected that the current minimum requirements set out should be applicable, these should be reviewed.</p> <p>Specifically, the calculation methodology for breather vent diameter (Section 5.11.5.7.1) does not define a K value for up to 10% hydrogen in natural gas mixture. Although, up to 10% hydrogen does not change the risk profile and allows suitable margin, hence existing installations should allow suitable safety margin.</p> <p><u>Natural ventilation to outside (5.13.2)</u></p> <p>This section describes the requirements for natural (not forced) ventilation outside. The methodology is expected to be okay for up to 10% hydrogen due to the limited change in risk profile of hydrogen and natural gas however a detailed review should be completed.</p>			
Suitability of the standard for up to 10% hydrogen			
<p><u>New Installations</u></p> <p>For application under 200 kPa the standard uses means of compliance. This takes a prescriptive approach to compliance for materials, fittings and components, installation of consumer piping, installation of gas appliances. This gives detailed design criteria that need to be met. Addition of up to 10% in the natural gas will affect the materials, joints, ventilations and mixture.</p> <p>For applications over 200 kPa the standard takes a performance-based approach. This method applies good engineering practice to design and installation. For applications over 200 kPa the standard will generally acceptable for up to 10% hydrogen for new installations as it is the installers responsible to ensure the compatibility with the selected gas.</p> <p><u>Compatibility with Existing Installations</u></p> <p>Generally, the suitability of materials, components, fittings and seals referenced by AS 5601 complaint installations under 200 kPa will be suitable for up to 10% hydrogen although a detailed review of AS/NZS 5601.1 Table 4.1 for compatibility is required. Testing being completed by industry (Evoenergy) will contribute to this.</p>			

Standard	AS/NZS 5601.1	Standards Committee	AG-006 – Gas Installations
<p>To achieve the same energy throughput an increase in flow rate will be required. For consumer piping systems that have limited capacity this could become an issue (although for up to 10% hydrogen in natural gas the Wobbe decreases about 2% so it is unlikely to lead to capacity restraints).</p> <p>Section 6.1.3 does outline a methodology for appliance “gas type” conversion that requires approval from the technical regulator. The exact detailed that a regulator would require would be on a case-by-case basis. For up to 10% hydrogen in natural gas significant technical regulator involvement would be required.</p>			
<p>Research currently being completed with respect to hydrogen that will support this standard</p>			
<p><u>Evoenergy test facility</u></p> <p>Evoenergy constructed a test facility. This is testing a variety of distribution and consumer piping materials and components. This testing is currently underway and preliminary results are expected at the end of 2019.</p>			

Appendix 3D AS/NZS 4563:2004 – Commercial catering gas equipment

Standard	AS/NZS 4563	Standards Committee	AG-001 – Gas appliances
Latest Revision	2004 (Reconfirmed in 2016)	Next Planned revision	No revision planned
Scope			
<p>AS 4563 applies to various types of commercial catering equipment intended for use with natural gas, town gas, liquefied petroleum gas and tempered liquefied petroleum gas. In particular the following appliances</p> <ul style="list-style-type: none"> • Boiling tables – Open and closed top, Chinese cooking tables • Salamanders, grillers and toasters • Solid grill plates and griddles • Barbecue grillers • Ovens • Boiling water units • Stockpots and brat pans • Atmospheric steamers • Fryers • Food warmers including bain-maries • Pasta cookers and rethermailzers. 			
Objective			
<p>The objective of AS 4563 is to provide manufactures, designers, regulatory authorities, testing laboratories and similar organisations with uniform minimum requirements for the safety, performance and use of commercial catering equipment.</p>			
Referenced Australian Standards			
<p>AS 1074, AS 1167, AS 1375, AS 1432, AS 1450, AS 1722, AS 1751, AS 1769, AS 1832, AS 1881, AS 2129, AS 2768, AS 3688, AS 4646, AS 5601, AS 1869, AS 300, AS 3100, AS 3350, AS 3500</p> <p>This standard is referred to in AS 345:2010 – Essential requirements for gas equipment.</p>			
Legislation referencing this standard			
<p>This standard is not directly referenced in legislation.</p>			
History of the standard			
<p>AS 4563 was prepared by AG-001 to supersede AS 4563/AG300-2003. There were minor amendments made during this revision.</p> <p>The previous revision (AG300-2003) was a series of individual standards that were merged into a single standard encompassing multiple types of appliances.</p>			
Work being completed by the standards committee with respect to hydrogen			
<p>No work completed at this stage.</p>			
Methodology			
<p>AS 4563 is a performance-based standard to meet the minimum requirements for safe design and construction of a commercial appliance.</p> <p>Section 2 of the standard defines the performance-based approach for design and construction of</p>			

Standard	AS/NZS 4563	Standards Committee	AG-001 – Gas appliances		
<p>the appliances. There are minor prescriptive elements.</p> <p>Sections 3 and 4 give details on the requirements of the test gas and minimum requirements for tests using limit pressures. It details on how to perform the testing and the minimum requirements to ensure that the tests are completed accurately</p> <p>Sections 5-15 gives specific prescriptive elements for particular appliances applications. These sections outline minimum design requirements for each appliance that is covered under the standard.</p> <p>AS 4563 has both normative and informative sections. Normative sections and terms are considered mandatory.</p>					
General technical impacts of hydrogen					
<p>The parameters and characteristics listed below have been identified as impacted by the addition of up to 10% hydrogen in a typical natural gas blend. The extent of the impacts is outlined in the “summary of technical implications” section of the report.</p> <p>“x” = specifically reference in AS/NZS 4563</p>					
Thermal Radiation		Wobbe Index	X	Stratification	
Light back	X	Methane Number		Air dilution ratios	
Flame speed	X	Sooting Index		Measurement of gas	
Yellow tipping		Flammability limit	X	Gas detection	
Moisture	X	Higher heating value		Hazardous Area	
NO _x emissions		Flame emissivity		Worker Safety	
Flame Temperature		JT cooling effect		Gas build-up in buildings	
Stoichiometric Composition		Minimum Ignition Energy		Auto ignition temperature	
Flame lifting	X			Radiation and dispersion	
Examples of specific considerations for hydrogen					
<p><u>Gas flow rate at ignition (3.9.2.2.1)</u></p> <p>Addition of 10% hydrogen changes the lower explosive limit. For applications where the gas concentration is near the 50% limit set in section 3.9.2.2.1 this may be an issue.</p> <p><u>Flame abnormality (4.5)</u></p> <p>The addition of up to 10% is proven to slightly affect the flame speed, which can in turn affects the flame stability and flame abnormality.</p> <p><u>Reference Gas (Table B1)</u></p> <p>For up to 10% hydrogen the reference gases listed in Table B1 are not likely to be suitable.</p>					
Suitability of the standard for up to 10% hydrogen					
<p>As the standard is currently written hydrogen of up to 10% is not considered in the listed gases. The definition for natural gas given is a primarily methane-based gas. This is in-line with the</p>					

Standard	AS/NZS 4563	Standards Committee	AG-001 – Gas appliances																												
<p>definition given in other standards (AS/NZS 5263 and AS/NZS 5601 etc.).</p> <p>Additionally, the test gases for natural gas (“N” and “S”) may not be suitable for up to 10% hydrogen. Table 1 below provides a summary of these test gases.</p> <p>Table 39 Taken from AS 4563 Table 1.2</p> <table border="1"> <thead> <tr> <th>Test Gas</th> <th>Methane</th> <th>Propane</th> <th>Nitrogen</th> <th>Air</th> <th>Heating value MJ/m³</th> <th>Relative density</th> <th>Wobbe Index MJ/m³</th> </tr> </thead> <tbody> <tr> <td>N</td> <td>97.5</td> <td>1</td> <td>1.5</td> <td></td> <td>37.8</td> <td>0.571</td> <td>50.0</td> </tr> <tr> <td>S</td> <td></td> <td>55</td> <td></td> <td>4.5</td> <td>52.1</td> <td>1.296</td> <td>45.7</td> </tr> </tbody> </table> <p>However, for methods of test that relate to flame stability such as MOT 4.5 and MOT 3.13.1 only the single “N” test gas is required to be tested. For 10% hydrogen in typical natural gas blends it was found that the practical value of the Wobbe would be between 43-49 MJ/m³.¹⁰³ With no lower limit tested the addition of up to 10% hydrogen could affect the flame stability.</p> <p>Section 2 of the standard outlines the design and construction of appliances. This section is generally performance-based rather than prescriptive and is likely suitable for up to 10% hydrogen. Minor revision may need to be made to sections to remove barriers.</p> <p>The methods of test are likely suitable for up to 10% hydrogen. They methods outlined are not restricted to a particular gas and with agreement on the test gas could be applied for a hydrogen/natural gas blend.</p>								Test Gas	Methane	Propane	Nitrogen	Air	Heating value MJ/m ³	Relative density	Wobbe Index MJ/m ³	N	97.5	1	1.5		37.8	0.571	50.0	S		55		4.5	52.1	1.296	45.7
Test Gas	Methane	Propane	Nitrogen	Air	Heating value MJ/m ³	Relative density	Wobbe Index MJ/m ³																								
N	97.5	1	1.5		37.8	0.571	50.0																								
S		55		4.5	52.1	1.296	45.7																								
Research currently being completed with respect to hydrogen that will support this standard																															
<p>There is currently no known testing and research being completed that can be specifically leveraged.</p> <p><u>Mondo Labs</u></p> <p>Mondo labs are testing a variety of small appliances and gas equipment. The results of their testing should be leveraged where possible.</p>																															

¹⁰³ GPA Calculation 19184-CALC-001

Appendix 3E AS/NZS 1869:2012 – Hose and hose assemblies

Standard	AS/NZS 1869	Standards Committee	AS-013 – Components used for Gas Appliances and Equipment.
Latest Revision	2012	Next Planned revision	No planned revision
Scope			
<p>AS/NZS 1869 specifies the requirements for hose and hose assemblies for:</p> <ul style="list-style-type: none"> • Liquefied petroleum gas, • Natural gas, • Town gas manufactured from oil productions, • Tempered liquefied petroleum gas, and • Simulated natural gas in transport, automotive, industrial and domestic application. <p>For hoses up to 100mm inside diameter and 2.6 MPa maximum working pressure.</p>			
Objective			
The objective of AS/NZS 1869 is to ensure performance, safety, durability and fitness for purpose of hose and hose assemblies in the gas industry.			
Referenced Australian Standards			
AS 1179, AS 1257, AS 1335, AS 1683, AS 2103			
Legislation referencing this standard			
This standard is not directly referenced in legislation.			
History of the standard			
AS/NZS 1869 was originally prepared in 1996. The 2012 revision included a number of updates to reflect new operating conditions and classes being used.			
Work being completed by the standards committee with respect to hydrogen			
No work completed at this stage.			
Methodology			
<p>Section 2 of the report sets out the minimum performance requirements of the hoses. It defines the classes of hoses and their allowable temperature and operating ranges.</p> <p>The appendix set-out the testing methodology for the various tests required to ensure compliance with the standard.</p>			
General technical impacts of hydrogen			
<p>The parameters and characteristics listed below have been identified as impacted by the addition of up to 10% hydrogen in a typical natural gas blend. The extent of the impacts is outlined in the “summary of technical implications” section of the report.</p> <p>“x” = specifically reference in AS/NZS 1869.</p>			
Thermal Radiation		Wobbe Index	Stratification
Light back		Methane Number	Air dilution ratios
Flame speed		Sooting Index	Measurement of gas
Yellow tipping		Flammability limit	Gas detection

Standard	AS/NZS 1869	Standards Committee	AS-013 – Components used for Gas Appliances and Equipment.		
Moisture		Higher heating value		Hazardous Area	
NO _x emissions		Flame emissivity		Worker Safety	
Flame Temperature		JT cooling effect		Gas build-up in buildings	
Stoichiometric Composition		Minimum Ignition Energy		Auto ignition temperature	
Flame lifting		Materials	X	Radiation and dispersion	
Examples of specific considerations for hydrogen					
N/A					
Suitability of the standard for up to 10% hydrogen					
<p>Currently the gases that are specific as covered under AS/NZS 1869 include natural gas but not a hydrogen/natural gas blend.</p> <p>The standard does not provide a materials selection list but rather requires the designer to select a material that is suitable for the gas service. A desktop review of the current hoses found the following materials:</p> <ul style="list-style-type: none"> • Stainless steel • NBR (Low pressure) <p>The test methods outlined in Appendix A to Appendix X are likely suitable for testing of a hydrogen/natural gas blend suitable hose.</p> <p><u>New applications</u></p> <p>For new hoses that are designed considering hydrogen the standard is likely to be suitable.</p> <p><u>Existing applications</u></p> <p>For existing hoses there needs to be further investigation into the materials compatibility and expected leakage rates. It is likely that most hoses will be suitable for up to 10% hydrogen blended with natural gas.</p>					
Research currently being completed with respect to hydrogen that will support this standard					
<p><u>Evoenergy test facility</u></p> <p>Evoenergy constructed a test facility. This is testing a variety of distribution and consumer piping materials and components. This testing is currently underway and preliminary results are expected at the end of 2019.</p>					