# Gas Exchangeability in Western Australia

## Gas quality specifications of interconnected pipeline systems

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WESTERN AUSTRALIA

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For further information, contact:

Mr Michael Soltyk
Economic Regulation Authority
Perth, Western Australia
Phone: (08) 9213 1900

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# Contents

# Introduction

This paper, which has been prepared by Mr Michael Soltyk, Manager Research and Modelling, has been issued in the interests of advancing the debate in economic regulation, recognising that matters of gas quality impact on access to gas pipelines. The paper presents the views of the Author and should not be taken as reflecting the views of the Authority, individual members of the Authority or other staff.[1]

Following a limited distribution of the draft paper, many written and verbal comments were received generally supportive of the views presented. This version of the paper seeks to reflect the comments received. A copy of this document, and to the extent possible, copies of the written comments[2] received are available from the Economic Regulation Authority web site.

Gas quality is required to be considered by the Authority as part of the terms and conditions of arrangements that provide third party access to natural gas pipelines in Western Australia. In so far as gas quality is a safety issue, the Authority relies on provisions in the *Gas Standards (Gas Supply and System Safety) Regulations 2000*, administered by Energy Safety of the Department of Consumer and Employment Protection. However, commercial aspects of gas quality extend beyond safety issues. Such commercial aspects are normally addressed as part of contracts for the supply and transportation of gas and for regulated pipelines in access arrangements. In addition contracts, including the Standard Shipper Contracts (**SSC**) on the Dampier to Bunbury Natural Gas Pipeline (**DBNGP**), currently include the terms and conditions including gas quality for transmission of gas in the pipeline.

The Authority is scheduled to commence the five year review of access arrangements for regulated pipeline systems in early 2009. The formal review for the first two of these systems is due to be completed in late 2009. As the time for undertaking reviews will be subject to strict time constraints, with time limits to be put in place under new legislation expected to be introduced early next year, the Authority intends progressing preliminary consultation at an early stage, particularly on complex issues such as gas quality. Section 2.1 of the *National Third Party Access Code for Natural Gas Pipeline Systems* provides for such consultation.

Gas quality has received attention in recent times because the domestic natural gas market in Western Australia is experiencing both a shortage of natural gas and relatively high prices. It is recognised that additional supplies of natural gas could be available to the domestic market if the gas quality specification for the DBNGP were made less stringent. In particular, natural gas from the Macedon field on the North West Shelf could be developed for domestic use if the existing gas quality specification were broadened.

Given the nature of the gas from the Macedon field, the cost of processing this gas is relatively high or may even be prohibitive at the existing gas quality specification.[3] Other fields with similar gas characteristics to that of Macedon face similar difficulties

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1 It is acknowledged that data of producing and undeveloped gas fields was provided by the Western Australian Office of Energy. Input and feedback in the course of the development of this paper from Mr Peter Kolf, Mr Peter Rixson and Ms Sylvia Soltyk are also gratefully acknowledged.

[2] With the approval of those that provided comments.

[3] It should be noted that even if Macedon gas is able to access the DBNGP, some treatment of the gas may be necessary to remove or reduce traces of compounds such as oxygen, sulphate, hydrogen sulphide and water.

in accessing the Western Australian domestic market. Accordingly, the question has been raised as to whether the gas quality specification for gas into the south west of Western Australia can or should be widened and what might need to be done before any changes are made to the specification. It is noted that the gas quality specification for the DBNGP is more restrictive than those of other Western Australian gas pipelines and is more restrictive than the "national" specification. This paper is primarily concerned with technical issues relating to gas quality and draws on both national and international experience in the management of gas quality.

The following matters are seen as relevant:

- the impact of gas quality on the diversity of the gas fields supplying the domestic market;
- the cost of gas processing on the one hand as compared with the cost of transporting gas on the other;
- the impact of gas quality on various commercial interests and the utilisation of gas resources; and
- the value of having a single national gas quality specification providing a consistent message to upstream and downstream interests including manufacturers of gas appliances.

One of the major obstacles to the introduction of a broader gas quality specification (or gas quality envelope) is the existence of older gas appliances, particularly appliances that were converted from the original town gas manufactured and distributed in areas around Perth up until the advent of natural gas around 34 years ago. The use of natural gas, specifically in these appliances, under a broadened gas quality specification could pose a safety hazard.

A comprehensive and robust program for testing and targeted withdrawal or modification of unsuitable old appliances can address any safety concerns that may exist. Such a program could be synchronised with a modification of the current gas specifications.

Immediate and future benefits to Western Australia of increased security of supply and direct gas-to-gas competition from a broadened gas quality specification could be expected to offset the costs of replacement and modification of old appliances.

This paper examines some options for the modification of gas specification limits. It also undertakes a brief analysis of the Australian Standard, a "wide" Western Australia gas specification[4] and the current regulated limits for natural gas transported through the transmission and distribution systems in Western Australia. The natural gas parameters of selected gas fields that have not yet been developed but have the potential to enter the Western Australian market and the gas of those which are currently producing are graphically presented.

## Natural Gas Parameters

Natural gas consists of hydrocarbons, inert gases and miniscule amounts of other compounds. Methane is the predominant component of natural gas. Heavier (higher)

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[4] Report by the Western Australian Office of Energy: "Review of the gas quality specification for the Dampier to Bunbury Natural Gas Pipeline, Western Australia " published in November 1995.

hydrocarbons for example ethane, propane, butane, pentane, and others appear in much smaller and diminishing amounts in natural gases.

Inert gases are defined as gases that do not contribute to the energy release during natural gas combustion. Nitrogen and carbon dioxide are the main naturally occurring inert gases.

Table 1 below provides a list of predominant gas components, their chemical symbols and the amount that, in practice, may be expected to occur in the majority of the natural gas fields.

**Table 1**

| Name | Chemical symbol | Abbreviated Symbol | Range [Mole%] |
|---|---|---|---|
| Methane | C1H4 | C1 | 70 to 98 |
| Ethane | C2H6 | C2 | < 15 |
| Propane | C3H8 | C3 | < 5 |
| Iso-Butane | C4H10 | IC4 | < 1.5 |
| N-Butane | C4H10 | NC4 | < 1.5 |
| Iso-Pentane | C5H12 | IC5 | < 0.5 |
| N-Pentane | C5H12 | NC5 | < 0.5 |
| Hexane | C6H14 | C6 | < 0.2 |
| Heptane | C7H16 | C7 | < 0.2 |
| Octane | C8H18 | C8 | < 0.1 |
| Nitrogen | N2 | N2 | < 10 |
| Carbon Dioxide | CO2 | CO2 | <20 |

Associated gas from oil fields often contain a higher proportion of heavy hydrocarbons.

Other gas impurities include traces of compounds such as oxygen, hydrogen sulphide, water and radioactive gases.

The terminology and parameters used in this paper have been defined in the International Standard ISO 6976 and the Australian Standard AS 4564-2005. A temperature of 15$^{o}$ C and absolute pressure of 101.325kPa represents the standard conditions or the metering reference conditions. All numerical values of gas parameters presented in this paper represent real (not ideal) gas values.[5]

To qualify and quantify any natural gas energy value, burning properties and the physical characteristics, a variety of quantitative measurements were developed.

These measurements include:

- chemical gas composition;

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[5] An Ideal gas has the following properties; 1 – gas particles have virtually no volume, 2 - collision between particles are elastic and 3 - there are no repulsive or attractive forces between particles. The equation of state for ideal gas is; PV = nRT where P is absolute pressure, V is volume, n is the number of particles, R is a gas constant and T is absolute temperature. Actual (real) gases at higher pressures do not obey the ideal gas laws. As a result, real gases are not as compressible at higher pressures as the ideal gas. The volume of a real gas is therefore larger than would be expected from the ideal gas equation at higher pressures. There are a number of real gas equations of state that use empirical factors to account for aberration from the behaviour of ideal gas. One of the real gas equations uses a compressibility factor Z and the real gas equation of state is PV = nZRT. Z is unique for every gas and varies with temperature and pressure.

- combustion indices; and
- physical properties.

It is generally accepted practice that the chemical composition of natural gas is measured in mole percent (**Mole%**).

Within developed countries, many methods define the combustion properties of natural gas and the choice of gas exchangeability indices varies not only between countries but also between jurisdictions within countries.

In the United Kingdom, three combustion properties of natural gas and some limits of gas components have been used to determine the suitability of gas for domestic consumption. These indices were developed by the British Gas Corporation and are graphically presented in the Dutton diagram.[6]

During the first half of the twentieth century, variations of combustion indices were developed in USA and Canada. Currently, the Wobbe Index complemented by the Weaver and American Gas Association (**AGA**) indices are used.[7] The AGA gas standard also restricts the level of heavier hydrocarbons and inert gases.

The physical parameters include:

- Higher Heating Value (**HHV**) [MJ/m3];
- Density (**D**) [kg/m3];
- Specific Gravity (**SG**) [kg/kg]; and
- Wobbe Index (**WI**) [MJ/m3].

The natural gas heating value represents the energy content in the standard volume. It is an important parameter as all transactions of natural gas refer to the energy value of the gas. However, the HHV alone is not a suitable parameter of gas exchangeability.

Gas density represents the mass of a defined volume of gas. The specific gravity is a mass ratio of the same volumes of the natural gas to the air at standard conditions of pressure and temperature. The value of the SG increases in proportion to the level of heavy hydrocarbons and inert gases.

The most important and widely recognised key parameter of natural gas exchangeability is the Wobbe Index. The WI is not a measured value but it is calculated as a ratio of HHV to the square root of SG.

The WI accounts for the flow and heat inputs of the gas through an orifice at constant pressure. It represents an amount of energy that can be delivered through a burner, thus it is a good indicator of gas combustion through the burner. For a given burner, changes in the WI are directly correlated to changes of heat generated per unit of time.

The Wobbe Index also can be used in the determination of the gas quality variation on the ability of a pipeline to transport energy. The energy gas flow is proportional to the volumetric flow and to the HHV. The volumetric gas flow in the pipeline is inversely proportional to the square root of the gas density. Hence thermal throughput through a

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[6] “A new dimension of gas interchangeability” by B.C. Dutton, Communication 1246 published in 1984.

[7] “White paper on natural gas interchangeability and non-combustion end use”, NGC + Interchangeability Working Group, February 28, 2005 and AGA Bulletin 36.

pipeline is proportional to the WI.  The variation of the heating value and the density of the gas also affects the operating cost of a compression plant.

The introduction of new gas sources combined with a broadening the gas specification, especially the WI limits, would increase the probability of gas quality variations.  These variations may have a negative impact on some industries that use natural gas as a heat source or as a “feedstock”.  Some industrial processes using gas as a feedstock cannot tolerate natural gas with a high level of inert gases, particularly carbon dioxide, however, a higher level of nitrogen can be tolerated.

A higher hydrocarbon content, even if it is compensated for by a high level of the inert gases in order to maintain an acceptable level of the WI, could lead to combustion problems in reciprocating engines and gas turbines.  Consequently, in some jurisdictions, additional restrictions were introduced that limited carbon dioxide and nitrogen levels.

Many jurisdictions, including Western Australia, use high and low limits of HHV and the WI coupled with other limits of chemical parameters to specify the acceptable envelope of natural gases that can be safely used.  The other limits usually relate to inert gases.  Maximum limits for both carbon dioxide and nitrogen are regulated in Western Australia.

In some jurisdictions, a limit of SG complements or replaces limits of the inert gases and HHV.  For example, the proposed transitional European gas specification limits only WI, SG and CO2 levels[8] and in New Zealand only the WI and SG limits are used in the determination of the gas specification envelope.[9]

There are other limits that restrict gas impurities, traces of other compounds and some physical parameters.  These limits may include; oxygen, hydrogen sulphide, water, radioactive gases, hydrocarbon dew point and other parameters such as temperature. The reasons for these limits and their values are generally established after a wide consultation with industrial users and other stakeholders.  This paper does not consider these other limits in any detail.

The analyses presented in this paper does not address the issues related to natural gas containing substantial quantities of hydrogen (H2).  For the purposes of gas modelling, it is assumed that the amount of hydrogen contained in natural gas is equal to zero or negligible.  It must be stressed that any level of hydrogen in natural gas may create unsafe combustion conditions like flashback, even for gases located well within regulated limits.

## Gas exchangeability

The transition from the historical single source of gas to multiple gas sources and the resulting gas quality that comes from the mixing of the various gases presents a technical challenge for all stakeholders involved in the gas market.

Gas exchangeability may be viewed as;

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[8] The European Gas Regulatory (“Madrid”) Forum in 2002 and Department of Trade & Industry – Workshop, London 10 March 2006 www.easee-gas.org.

[9] New Zealand Standard, NZS 5442:1999.

*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.*

Exchangeability of natural gas can only be described in terms of specific technical measures that delineate an acceptable spectrum of gases. The application of these measures must be relevant to gas users without unreasonably disadvantaging gas producers or transporters. The best performance of gas appliances is usually achieved by natural gas being limited to a narrow range. However, the cost of processing and supplying gas within a narrow band can be very high or even prohibitive.

Any gas specification must therefore represent a balance between the best performance of gas appliances and the cost of gas supply. If the gas specification is too narrow, it represents a barrier for the creation of an effective and efficient gas market by limiting gas sources and increasing the gas processing cost. Alternatively, a broad gas specification can increase safety risks and lead to efficiency losses. A well balanced gas specification can be regarded as one that offers the broadest possible range of natural gas parameters while maintaining safety, reliability, efficiency and environmental standards.

This broadest gas specification, applicable to all regulated and unregulated distribution and transmission natural gas pipelines, was recognised by the greater majority of those that responded to the draft paper as one of the fundamental conditions to establish a transparent and competitive gas market without imposing artificial barriers for gas to gas competition.

## Background of gas quality in WA

Historically, the gas specifications of all major gas transmission systems in Western Australia had been based largely on the original contracts between the pipeline owners/operators and the gas suppliers.

Around 100 years ago, the first gas used in Western Australia was manufactured from coal. The manufactured gas was distributed in Fremantle, Perth and Albany. The Perth and Fremantle distribution systems were converted to natural gas in 1973 supplied from the Perth Basin via the Western Australian Natural Gas (**WANG**) transmission system. All gas appliances using manufactured gas were replaced or converted to natural gas. The Albany distribution system was first converted from coal based gas to a mixture of the liquefied petroleum gas (**LPG**) and air (synthetic gas or tempered LPG (**TLPG**)). Currently pure LPG is distributed in Albany.

The WANG pipeline was constructed in 1972 and connects the Dongara gas field with Perth and Pinjarra customers. This Pipeline system is currently known as the Parmelia pipeline and transports gas from various fields in the northern Perth Basin to the distribution system in Perth and to a number of major industrial customers in the South West region of Western Australia. The Parmelia pipeline has been interconnected with DBNGP at the beginning of the Parmelia line since 1994.

With the supply of gas from the Perth Basin declining, a new supply became available from the Dampier to Bunbury Natural Gas Pipeline (**DBNGP**) in 1984. From this time until 2001, the DBNGP exclusively supplied the Perth distribution system. The

Parmelia pipeline was, however, subsequently reconnected to the Perth distribution system. A mixture of gases from DBNGP and Parmelia pipelines currently supply some areas of the Perth distribution system.

From 1984 to 1998, the State Energy Commission of Western Australia (**SEC/SECWA**) owned and operated the gas-reticulated system in Perth and the Dampier to Bunbury Natural Gas Pipeline. The gas was sourced from the domestic gas plant (**Woodside**) and owned and operated by the North West Shell Joined Venture Partners (**NWS JVP**).

Between 1992 and 1994, two new natural gas transmission pipeline systems connected to the DBNGP. The gas quality from the Harriet gas pipeline system was well within the existing gas specification, however, the gas from the Tubridgi gas pipeline system was well outside the SECWA gas specification. As the quantity of Tubridgi gas was relatively small, the decision was made to accept the Tubridgi gas into the DBNGP utilising a “mixing space” of the upstream gases.

This mixing space was available owing to relatively high levels of liquid petroleum gas (**LPG**) in the gas entering the pipeline and the historically relatively high level of heavier hydrocarbons in the Woodside gas. In addition, a minimum level of LPG was also required to be in gas entering the DBNGP for supply to Wesfarmers’ LPG extraction plant located at Kwinana.

The DBNGP gas system had three gas specifications:

1) Category A Gas, gas entering the gas transmission system:

2) Category B Gas, gas delivered to customers located between the domestic gas plant and the LPG extraction plant located in the Kwinana Industrial Area; and

3) Category C Gas, gas delivered to customers located downstream of the LPG extraction plant.

The DBNGP was privatised and is currently operated by DBP WA Transmission Pty. Ltd.

The Gas Goldfield Pipeline (**GGP**) was commissioned in 1996. It transports the gas from the Harriet gas pipeline to industrial customers located between Newman and Kalgoorlie/Kambalda. Currently, the DBNGP and the GGP are interconnected at the end of the Harriet pipeline. In 2004, a pipeline from Kambalda to Esperance was constructed as an extension of the GGP system. This pipeline supplies gas to a power station and distribution system in Esperance.

All three interconnected transmission systems have different gas quality specifications.

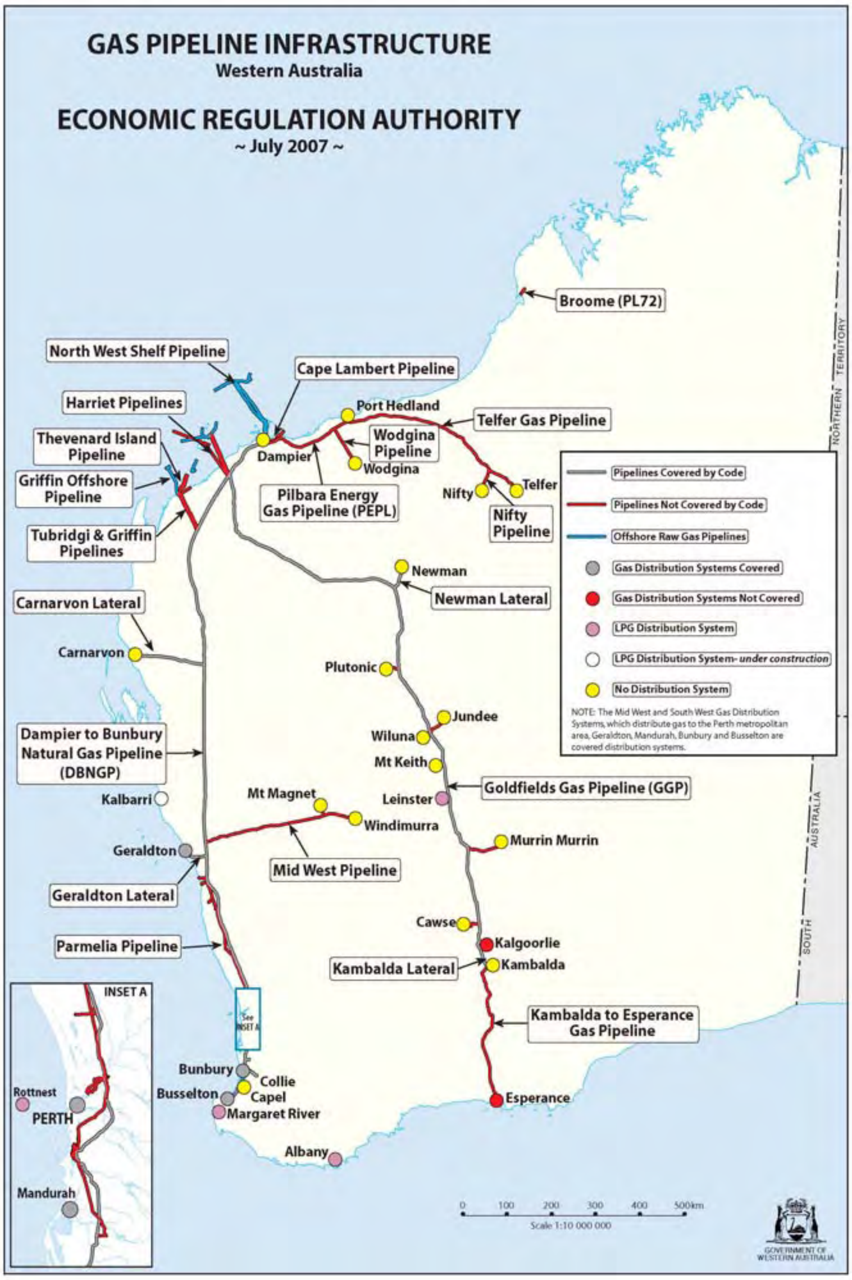
There are also three natural gas distribution systems:

- Mid West and South West distribution systems. These distribution systems are located between Perth and Geraldton in the north, and Perth to Busselton in the South, and takes gas from DBNGP and Parmelia systems;
- Esperance; and
- Kalgoorlie gas distribution system.

The Esperance and Kalgoorlie systems are fed via the GGP system.

All natural gas distribution systems in Western Australia are covered by a gas quality specification set out in the *Gas Standards (Gas Supply and System Safety) Regulations 2000* (**WA Safety Regulations 2000**). The most stringent of these regulations and the gas specification applicable to DBNGP governs the gas specification for Perth distribution system. Consequently, the Perth distribution gas specification envelope is identical to the DBNGP envelope. This is the most restrictive of any natural gas specification envelope in Western Australia[10].

The following map shows the gas pipeline infrastructure in Western Australia.



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[10] The limits of oxygen, hydrogen sulphide, water, radioactive gases, hydrocarbon dew point may vary between different gas specifications.

In addition, there are two unregulated pipelines that are connected to the DBNGP system. Mid West Pipeline from Geraldton to Windimurra was commissioned in 2000. Pilbara Pipeline from Karratha to Port Hedland was commission in 1994 and extended to Telfer, Nifty and Wodgina between 2001 to 2005. The Authority has no information on the gas specifications applicable to these pipelines. However, as both pipelines are connected to the DBNGP, it is most likely, that gas specifications identical to the DBNGP specification apply to these pipelines.

In 1994, The Minister for Energy in Western Australia requested that the Office of Energy (**OOE**) review the gas quality specification for the DBNGP. A Standing Committee of Gas Quality was established. After wide consultation with major industries and other interested parties, the report, "*Review of the gas quality specification for the Dampier to Bunbury Natural Gas Pipeline, Western Australia*" was published in November 1995.

The report recommended some immediate changes to the parameters of the gas specification with other parameters to be changed over a period of time. It was intended that the final, "wide" gas specification be implemented by 2005.

A survey, undertaken by SECWA in 1993, indicated that there were around 27,000 "old" gas appliances that could not be safely used beyond the boundaries of the then gas specification for the distribution system. The report recommended that the "old" appliances should be identified and modified or replaced before the gas specification is widened. The results of this survey and the testing of the "old" appliances (some of them converted from the town gas) led to the rejection of the "wide" gas specification in 1995.

The recommendation that old gas appliances should be identified and modified or replaced was not implemented and the safe operation of the existing old gas appliances was and still is one of the major reasons for the reluctance of the regulating authorities to widen the current gas specification. The current number of old appliances is unknown.

Between 2000 and 2007, the majority of the natural gas transmission and distribution systems in Western Australia were regulated. On 13 March 2002, the regulatory coverage of the Parmelia pipeline was revoked. The principal parameters of the currently regulated and 1995 "wide" gas specifications are shown in Table 2 below.

**Table 2**

| Parameter | DBNGP AA[11] | Perth Distrib. AA[12] | Safety Reg. 2000 | GGP AA[13] | Parmelia [14] | Wide |
|---|---|---|---|---|---|---|
| Min. Higher Heating Value [MJ/m3] | 37.0 | 37.0 | 37.0 | 35.5 | 35.1 | 35.1 |
| Max Higher Heating Value [MJ/m3] | 42.3 | 42.3 | 42.3 | 42.5 | 42.3 | 42.3 |
| Min Wobbe Index [MJ/m3] | 46.5 | 46.5 | 46.5 | 46.0 | 46.0 | 46.0 |
| Max Wobbe Index [MJ/m3] | 51.0 | 51.0 | 51.0 | 51.5 | 51.5 | 51.5 |
| Max Carbon Dioxide [Mole%] | 4.0 | 4.0 |  | 3.6 | 4.0 | 4.0 |
| Max Inerts [Mole%] | 7.0 | 7.0 |  | 7.0 | 7.0 | 7.0 |

Wobbe Index (WI), Higher Heating Value (HHV), Carbon Dioxide (CO2) and Inert Gases (CO2 and N2) are the major physical and chemical gas parameters.  The limits of these parameters delineate the gas specification envelope.

It should be noted that the gas quality specification envelope applicable to the Parmelia system is the same as the 1995 proposed “wide” specification envelope. DBNGP and all distribution systems are covered by the same gas specification envelope and GGP has a unique gas specification envelope.

The gas impurities including traces of chemical compounds in the currently regulated gas specifications are shown in Table 3 below.

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[11] Approved Revised Access Arrangement Terms and Conditions for Reference Services **15** December 2005: http://www.era.wa.gov.au/cproot/3673/14613/Approved_Revised_AA_Appendix_1_T_and_C_all.pdf

[12] Most stringent of :

a) Gas Standards (Gas Supply and System Safety) Regulations 2000,

http://www.slp.wa.gov.au/statutes/regs.nsf/3c0405a7241b5fe648256810003b1b1d/bb703ca7a53c52474825691c0017f9a6?OpenDocument or any approved access arrangement.

[13] Goldfields Gas Pipeline Approved Access Arrangement - Appendix 3 General Terms and Conditions 14 July 2005;

http://www.era.wa.gov.au/cproot/3460/13761/20050714%20GGT%20AAGTC400%20Final%20Approved.pdf

[14] Parmelia Pipeline Access Arrangement General Terms & Conditions 2000 15 December 2000:

http://www.era.wa.gov.au/cproot/4224/16805/ParmeliaPiplineAAGTC.pdf

**Table 3**

| Parameter | DBNGP AA | Perth Distrib. AA | Safety Reg. 2000 | GGP AA | Parmelia | Wide |
|---|---|---|---|---|---|---|
| Unodorised Gas, Max Total Sulphur [mg/m3]r | 10 | 20 | 50 | 10 | 10 | 10 |
| Odorised Gas, Max Total Sulphur [mg/m3]r | 20 | 20 | 50 |  |  | 20 |
| Max Hydrogen Sulphide [mg/m3] | 2 | 4.6 |  | 5 | 4.6 | 2 |
| Max Oxygen [Mole%] | 0.2 | 0.2 |  | 0.2 | 0.2 | 0.2 |
| Max Water [mg/m3] | 48 | 100 |  | 48 | 100 | 48 |
| Hydrocarbon Dew Point [deg C] | <0 |  |  | 0 | 10 | <0 |
| Max Radioactive Components [Bq/m3] | 600 | 600 |  | 600 | 600 | 600 |

It is important that the specification limits of these impurities should also be standardised when considering other limits of the gas specification. However, the analyses presented in this paper do not address the issue of natural gas impurities.

# Current situation of natural gas supply in WA

The volume of natural gas consumed in Western Australia has more than doubled in the last 20 years. Currently, the demand for new gas in the Western Australian market exceeds available gas supplies in the domestic market with the result that gas unit prices for new contracts have increased significantly over the last several years.

Western Australian electricity generation, mineral processing and mining activities account for approximately 90% of natural gas usage and the balance of gas is consumed by the residential and small industrial customers.

This paper is not intended to provide a comprehensive analysis of the natural gas shortage. However, the current shortage of gas is likely to have a detrimental economic impact on existing industrial users and on the development of new projects.[15]

The combination of a shortage of gas and high gas prices reduces the opportunities and choices of energy sources for industry in WA. It has already impacted on the fuel mixture balance for power generation. Recently, Synergy announced that it only secured half of the required 400MW of additional power for the South West grid with the other 200MW postponed till next year. The reasons for this delay are understood to include the current high domestic gas price and the expectation that this price will fall as new competitive gas sources enter the gas market.[16]

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[15] Report for the dogmas alliance “Natural gas demand forecast for Western Australia and economic impact of potential supply shortages” published by Economic Consulting Services, August 2007.

[16] Page 12, The West Australian, 14 February 2007.

Domestic gas supplies are currently constrained in Western Australia and gas prices have increased significantly. It is anticipated that the higher gas prices will encourage new sources to become available to the domestic market which should see prices stabilising in the medium to longer term.[17]

The North West Shelf domestic gas plant has reached its capacity and has to be upgraded to accommodate additional gas quantities.

During the last 25 years, many substantial reserves of natural gas have been discovered in the Carnarvon Basin and only a few of them have been developed. However, the main opportunity for these supplies of natural gas is for them to be liquefied (**LNG**) and exported. Only a relatively small quantity of gas is delivered to the Western Australian market.

As energy prices increase, the LNG market becomes more lucrative and there will be greater commercial pressure to see domestic prices reflect net back LNG prices.

There is therefore an opportunity for new gas sources to enter the market. However, the gas parameters from some of the potentially new fields are outside the boundaries of the current regulated gas specification envelopes and the cost of gas processing to meet the existing specifications would be likely to further discourage the development of these fields.

Recently, it has been suggested that Western Australia adopt the national gas specification set by Australian Standard AS 4464-2005. The national gas standard has much broader limits than any gas specification applicable in Western Australia. The national gas specification is presented in Table 4 below. The analysis presented in this paper indicates that the national gas specification is unlikely to be suitable for Western Australia.

This paper provides an analysis of natural gas specifications currently applicable in Western Australia as compared with the national specification. It considers modifications of current natural gas specifications and replacing them with one gas quality specification that could apply to all transmission and distribution systems in Western Australia or even in Australia. The implementation of these modifications would promote the entry of natural gas from more fields by achieving a balance between safety, appliance efficiency and environmental performance while reducing or minimising the cost of gas processing.

## Dutton Diagram

There are many methods that graphically illustrate the various gas quality properties for the purposes of depicting gas quality standards. European countries use different approaches including the Dutton method in the United Kingdom (**UK**), the Delbourg method in France, Holmqyist method in Sweden, Shuster method in Germany and Van der Linden method in Holland.[18] Grumer, Harris and Rowe developed a graphical method used in USA.

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[17] Discussion paper "Gas Issues in Western Australia" published by Economic Regulation Authority, June 2007

[18] Gas Technology Institute, "Natural Gas Composition and Fuel Quality" Information Report, 11 February 2005.

For historical reasons, some Australian jurisdictions, including Western Australia, have used the Dutton method and Dutton diagram to compare natural gases from different fields. This paper examines the usefulness of the Dutton diagram when other natural gas properties other than British combustion indices are used.

In the 1970s, the United Kingdom experienced a gas reserves decline in the North Sea and the British Gas Corporation considered the possibility of importing gas from the Norwegian fields. The gas from the Norwegian fields had different characteristics. In 1984, Mr B. C. Dutton from the British Gas Corporation published a paper[19] that proposed a method of comparing gases from different fields.

Dutton concluded that any natural gas can be represented by an equivalent gas comprising only three components; methane, propane and nitrogen.[20] All hydrocarbons of the original gas are converted to methane and propane equivalents with an equivalent ideal gas volume and average number of carbon atoms per molecule being the same as in the original gas.

The carbon dioxide of the original gas is converted to equivalent nitrogen. The value of the Wobbe Index of an equivalent gas is preserved by the conversion factor of carbon dioxide to nitrogen. In other words, the nitrogen equivalent when mixed with non-inert equivalent components produces an equivalent gas with the same Wobbe Index as the original gas.

He also proposed three indices related to the properties of gas combustion that could be used in the determination of an acceptable range of gases that can be used safely in UK gas residential appliances.

Three indices proposed by Dutton were determined by using real appliances. The mathematical equations describing these indices represent empirical relationships between indices and other physical and chemical gas parameters. These indices are the basis for the determination of acceptable combustion limits and they can be graphically represented in the Dutton diagram by three limit lines (Figure 1) below.

These three indices are:

1) Incomplete Combustion Factor (**ICF**);

2) Soot Index (**SI**); and

3) Lift Index (**LI**).

The X-axis of the Dutton diagram represented Propane and Nitrogen Equivalent and the Y-axis represented the Wobbe Index (**WI**).

In addition, there are two lines that constitute physical natural gas boundaries. A gas containing only hydrocarbons (no inert gases) represents the first physical boundary line (C1+C3) and a gas containing only methane and inert gases (C1+N2) represents the second physical boundary line.

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[19] "A new dimension of gas interchangeability" by B.C. Dutton, Communication 1246 published in 1984.

[20] The original Dutton Diagram was a three dimensional diagram where hydrogen was represented on the Z-axis. This diagram is predominantly used as a two dimensional graph. For the purpose of this paper an assumption is made that the level on hydrogen in the natural gas equal to zero.

As the LI is a nearly a horizontal line on the Dutton Diagram, this index was replaced by the minimum WI limit of 47.2MJ/m3 and recently the Dutton limits were supplement by a maximum WI limit of 51.41MJ/m3. Within an acceptable range of natural gas, this high WI limit is a very close approximation of ICF.

When using old gas appliances in the United Kingdom, the combustion of any natural gas with a WI above the Soot Index line and/or above the Incomplete Combustion Factor line may generate excessive levels of carbon monoxide, nitrogen oxides and soot.

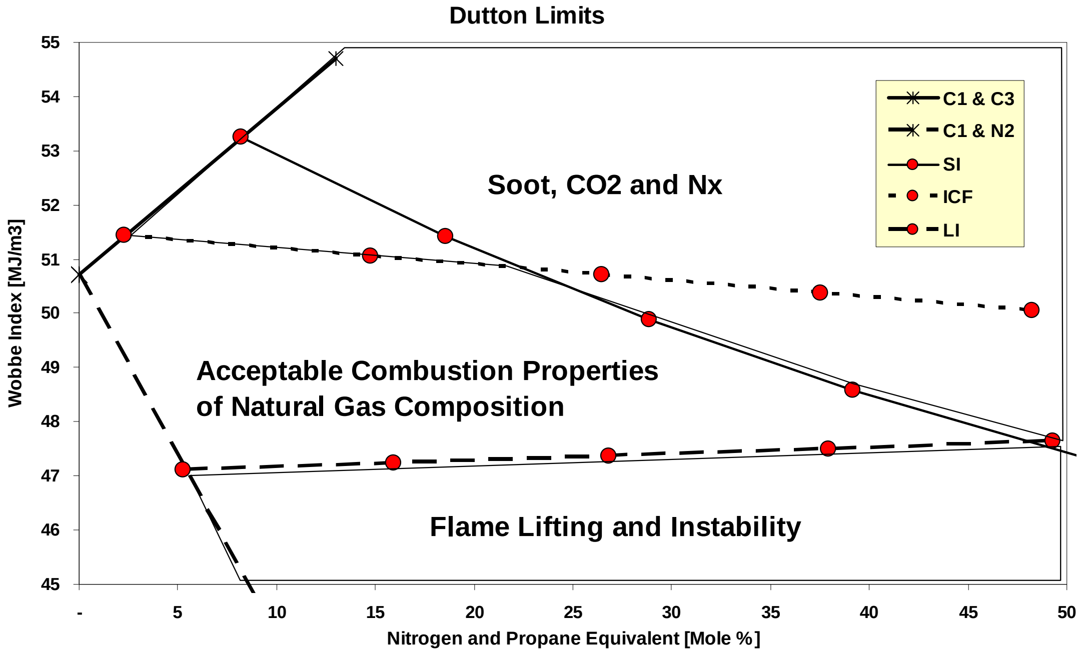
Flame lifting, blowouts, increased level of carbon monoxide generation and general flame instability can be expected from the combustion of any gases with the parameters located below the LI line.

Three lines depicting the indices (ICF, SI and LI) and two gas physical boundary lines ((C1+C3) and (C1+N2)) delineate a gas specification or gas envelope in Figure 1. Gases lying within this gas envelope are deemed to be interchangeable and can be commingled with other natural gases within the United Kingdom (**UK**) network and may be used in UK residential appliances without risk of unsafe combustion.

The Dutton method of the determination of gas exchangeability and the proposed limits has been accepted by British Gas and were used in the determination of the UK gas standard.[21]

The Dutton Diagram with the UK limits and the gas boundary lines is shown in Figure 1 below.

**Figure 1, Dutton diagram and Dutton limits.**



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[21] Schedule 3 of Gas Safety (Management) Regulations 1996 or GS(M)R.

The UK is the only country to use ICF and SI as the limiting characteristics of the gas specification envelope.  Pre 1993, gas appliances dictated the current UK limits.

Similarly to Western Australia, some of the “old” appliances were converted from the town gas.[22]  In many respects, the UK gas specification is more restrictive than other European countries.

All gas appliances sold in Europe after 1993 must comply with the Gas Appliances Directive 90/396/CEE or “GAD” and the natural gas outside the UK gas regulated limits can be safely used in these appliances.

Despite the fact that Australian jurisdictions use limits of gas physical and chemical parameters other than the combustion limits used in the United Kingdom, some Australian jurisdiction adopted the Dutton method to graphically present gas qualities.

There are historical reasons the method developed for British appliances is used in Australia.  The gas industry recognised the usefulness of the Dutton diagram in assessing the natural gas compliance with the regulated limits.

However, the Dutton diagram is one of many possible graphical presentations that can be used.  The Dutton Diagram was specifically developed to present British limits like Incomplete Combustion Factor, Soot Index and Lift Index.  However, the presentation of other than British parameters using the Dutton diagram my be difficult to understand, misinterpreted or confusing.

In addition, Dutton’s X-axis of propane and nitrogen equivalent is not an intuitive gas property and is difficult to relate to the specific properties of natural gas.

Presentation of HHV using the Dutton approach and diagram introduces complexities that can lead to misinterpretation.  This is illustrated in Figure 2 below showing both upper and lower HHV limits.

The difficulty that arises in using the Dutton representation is that for a given value of HHV and at each point along the horizontal axis there will be one value of the WI for gases containing nitrogen only as the inert gas and a different WI value for gases containing carbon dioxide only as the inert gas.

Hence, two gases having the same HHV and the same Nitrogen and Propane Equivalents are presented in Figure 2 by two different lines when the first gas that has only nitrogen as the inert gas and the second gas has only carbon dioxide as the inert gas.

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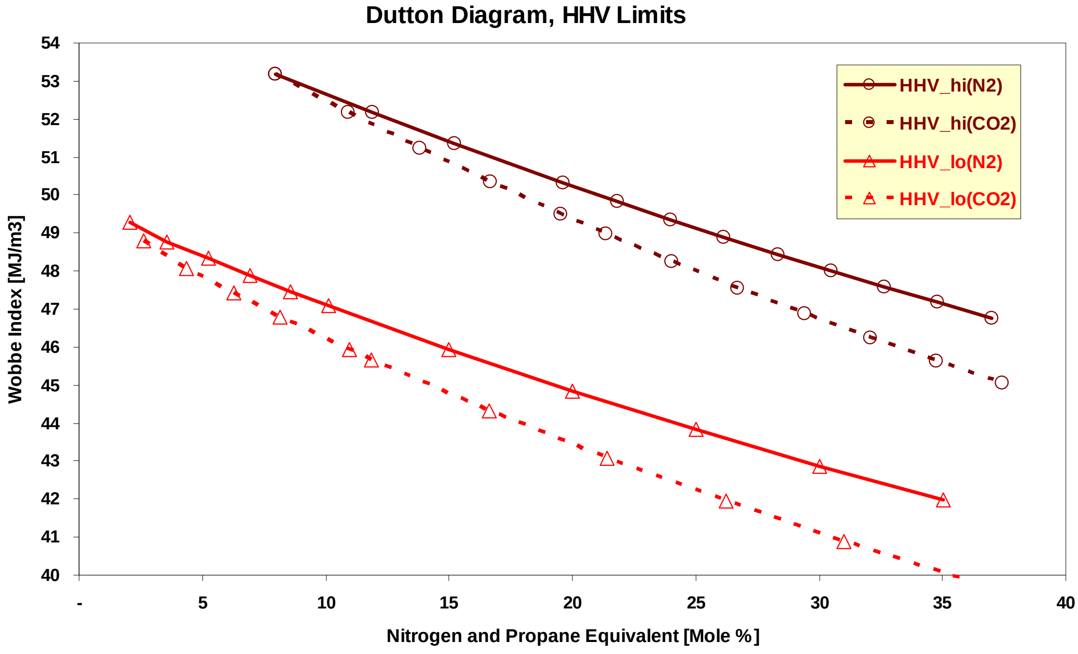
[22] Town gas was manufactured from coal.

**Figure 2, Dutton diagram with HHV limits.**

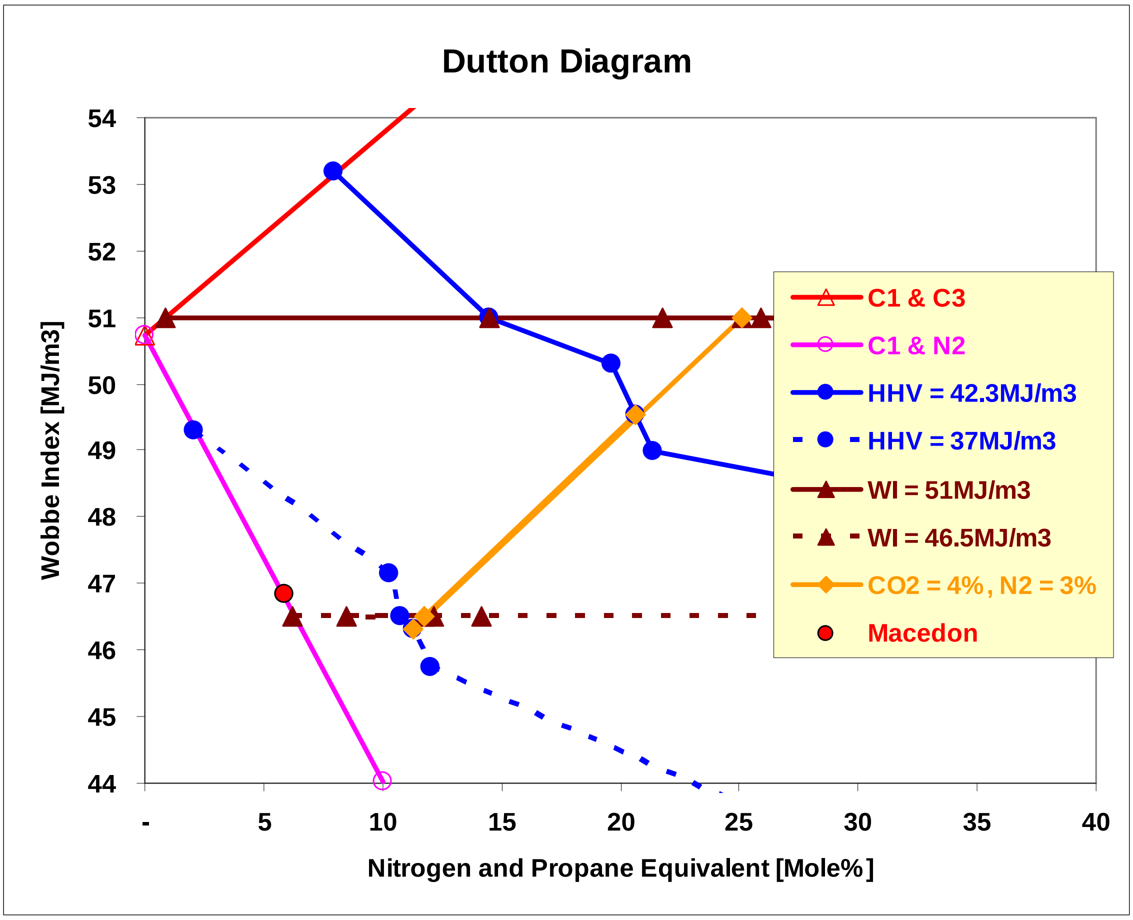


At each of the HHV limits (either HHV_hi or HHV_lo in Figure 2 above), the lines start at the same point where the level of inert gas is zero. The HHV lines diverge with increasing amounts of inert gases and/or hydrocarbon components.

This double representation of the HHV limits creates additional difficulties when a gas envelope is determined for a gas specification that has HHV, N2 and CO2 limits.

The current regulated limits and the gas envelope delineated by these limits of the gas distribution network and the DBNGP are presented on a Dutton diagram in Figure 3 below.

Figure 3, Dutton diagram with DBNGP regulated limits.



The irregular characteristics of the maximum and minimum HHV lines are a result of the transition from the N2 limit to a combination of CO2 and N2 limits for the same HHV values.

Gas density and specific gravity display similar double representation characteristics as HHV when presented on the Dutton diagram.

## Proposed Alternative Delineation of the Gas Specification Envelope

Many developed countries, including Australia, adopted some combination of the following limits of the major physical and chemical parameters of natural gas that delineate a gas envelope:

1) minimum and maximum Wobbe Index;
2) minimum and maximum Higher Heating Value;
3) maximum Inerts;
4) maximum Carbon Dioxide;
5) maximum Nitrogen;

6) minimum and maximum Specific Gravity; and

7) minimum and maximum Gas Density.

All of these major gas quality limits and the gas envelope created by these limits may be graphically presented on a diagram with the WI on the Y-axis and other gas parameters or some combustion index on X-axis.

As elsewhere discussed in this paper, the WI is generally accepted as the most important gas exchangeability parameter. The WI, sometimes called the “exchangeability factor”, is commonly recognised physical parameter of gas quality. Its high and low limits define two boundaries of the acceptable gas envelope and indicate combustion properties beyond which unsafe operation conditions exist. Other boundaries can be represented by any other gas parameter or gas combustion property or index.

The likely consequence of exceeding the high limit (max WI), would be excessive soot deposition and increased emission of carbon monoxide and nitrogen oxides. The likely consequence of falling below the low limit (min WI) would be flame lifting, blowouts, release of unburned hydrocarbons and increased carbon monoxide generation.

It is also recognised by the gas industry in all developed countries that the WI, on its own, is not a sufficient determining factor of gas exchangeability because it does not fully predict combustion behaviour.

Another important gas property is HHV. The likely consequence of gas exceeding the high limit of HHV (max HHV) is problems with combustion when natural gas is used as a fuel in reciprocating engines or gas turbines. When used as an engine fuel, natural gas containing substantial higher hydrocarbons, even if compensated for by a higher level of inert gases, may result in engine knock or gas auto ignition.

The performance, reliability and efficiency of some of the processes and equipment using natural gas as a feedstock or for heat generation may also be impacted by high levels or variations in inert gases and/or high levels of heavier hydrocarbons.

In addition, the presence of CO2 and moisture pose a risk to the integrity of gas transmission systems and other gas facilities.

In recognition of these factors, nearly all jurisdictions outside of the UK have placed restrictions on the marketing of natural gas that has a high level of higher hydrocarbons and inert gases by limiting the maximum allowable level of HHV, N2 and CO2.

The properties depicted by the upper limits of HHV and inert gases can be represented by a high SG limit, as the SG of natural gas increases in proportion to the increased level of heavy hydrocarbons and inert gases.

Both WI and SG can be used to define the combustion properties of natural gas and directly relate them to the capacity of gas pipeline systems.

Recognising the importance of the WI and the SG of natural gas, both parameters are used as a practical approach to graphically presenting the limits of the physical and chemical gas parameters that demarcate the bounds of exchangeable natural gases.

In view of this, WI and SG are used as the parameters specifying the vertical and horizontal axis of all further charts in this paper.

Both parameters are widely used by the gas industry.  For example, Gaz de France used WI and SG parameters to graphically show gases from different sources despite the fact that the most popular graphical presentation used in France is the Delbourg method published in 1971.[23]  The Delbourg method uses a combustion potential index as the horizontal axis with the WI on the vertical axis.  The combustion potential index of natural gas is related to flame speed.

The graphical presentation using WI versus SG delineates the operating envelope of natural gases and it is a functional and simple alternative to the Dutton or any other diagram when generally accepted physical and chemical parameters of natural gas like WI, HHV, N2, CO2, D and SG are used.

In addition, there are two physical natural boundaries that limit the specification of natural gas.  The first boundary represents gases containing only hydrocarbons (C1+Cn) and the second represents gases containing methane and nitrogen (C1+N2). Natural gas does not exist to the left of these boundary lines.  A natural gas containing methane only has WI of 50.7244MJ/m3 and SG of 0.5548kg/kg and exists at the intersection of the two physical natural boundaries referred to in this paragraph.

Using the WI versus SG graph eliminates double representation of HHV, D and SG limits associated with the Dutton method.

The Wobbe Index versus Specific Gravity diagram (referred to in this paper as the “S Diagram”) visually portrays any natural gas and gas operational envelops.

The current regulated limits of the gas distribution network and DBNGP and the envelope delineated by these limits are presented in Figure 4 on the S Diagram below.

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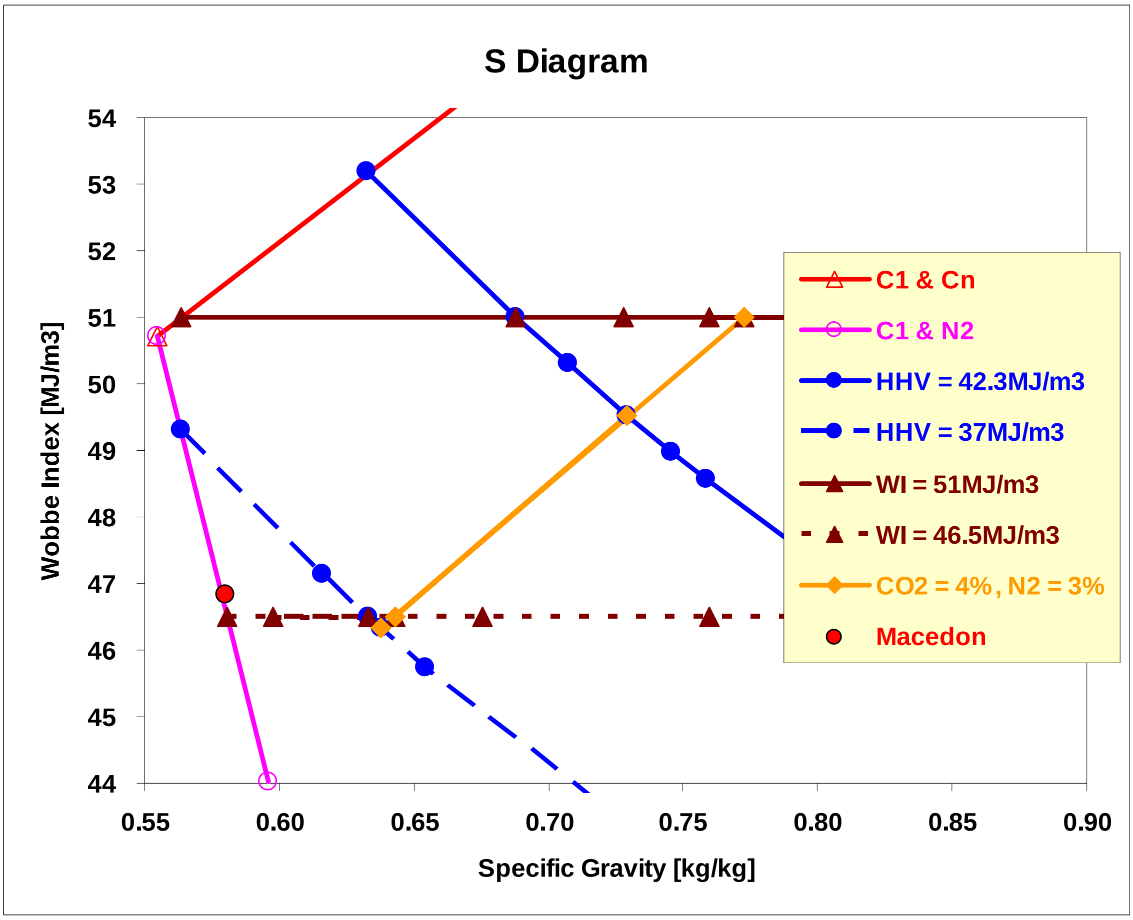
[23] Gaz de France, “Gas Interchangeability, experience with many sources of LNG & pipeline gas in France and Europe”.

**Figure 4, S Diagram with DBNGP regulated limits.**



For illustration purposes, natural gas from the Macedon field is also shown This gas is outside the current boundaries of the DBNGP gas specification as its HHV is too low.

There are several advantages of presenting the gas envelops and any natural gas using the S Diagram:

- any natural gas can be directly presented;
- calculation of the SG and Real WI values are well known;
- natural gas composition does not need to be converted to an equivalent gas using the Dutton approach;
- any chemical or physical parameter limit has its own and unique line;
- all of the limit lines are smooth; and
- Both WI and SG parameters have intuitive physical meanings.

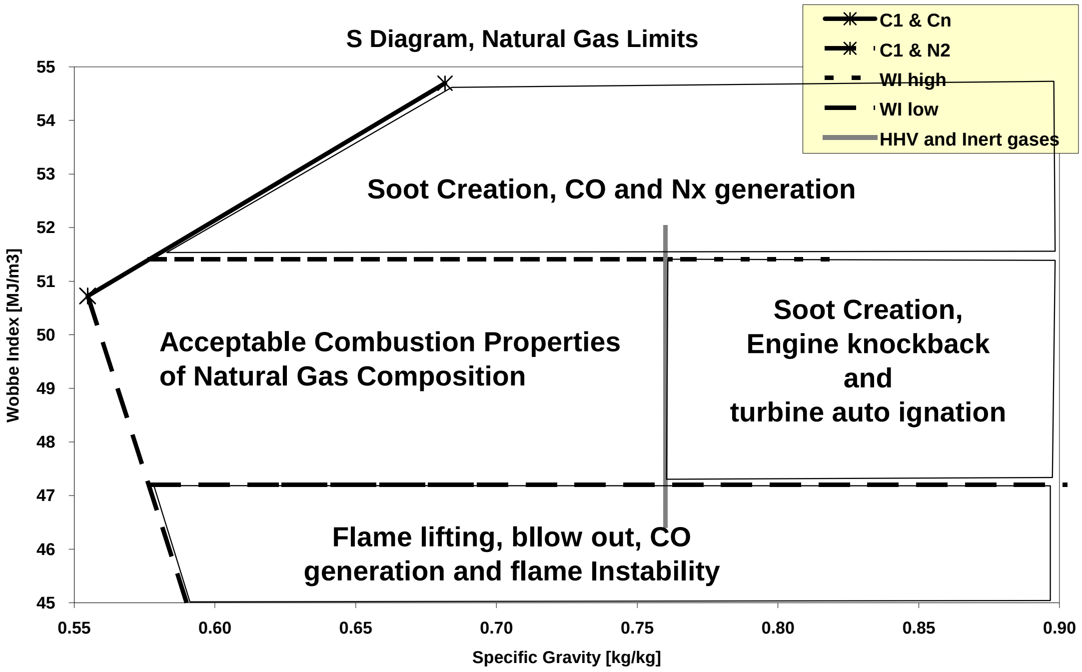
The S Diagram can also be use to present an area of the acceptable combustion properties of natural gas and to delineate a spectrum of exchangeable natural gases.

A high level of inert gases may not be acceptable by some industrial processes using gas as a feedstock and a high level of heavier hydrocarbons cannot be used as an engine fuel. The Dutton limits were not designed to address these restrictions of natural gas utilisation.

Many jurisdictions outside the United Kingdom restrict gas entry to the market by regulating other limits including maximum levels of HHV and inert gases.

Figure 5 below illustrates the limits of WI and other physical parameters of natural gas using the S Diagram. Other limits are notionally represented by a single vertical line.

**Figure 5, S Diagram with non-specific limits.**



The gas parameters used to create this graph have been selected for illustration purposes only and they are not intended to represent any particular gas specification or limit.

The S Diagram can also be used to graphically present the UK combustion indices.

## WA Gas Specifications

There are three major natural gas transmission systems in Western Australia; DBNGP, GGP and the Parmelia pipeline transporting gas to Pilbara, the Mid West and South West of Western Australia. Each of these are covered by different gas quality specifications. The most restrictive of these are those applying to the DBNGP and the Mid West and South West Gas Distribution Systems.

The existence of these different gas specifications has historical roots. All gas transmission systems are interconnected. DBNGP and Parmelia supply gas to the single Perth gas distribution system and the Kalgoorlie and Esperance gas distribution systems are connected to the GGP system.

The lack of one uniform gas specification applicable to all natural gas transmission and distribution systems in Western Australia creates an artificial barrier to the exchange of natural gas between systems.

With the exception of Tubridgi gas, all other gases currently transported through gas systems in Western Australia originate in a combination of fields and are subject of gas processing.

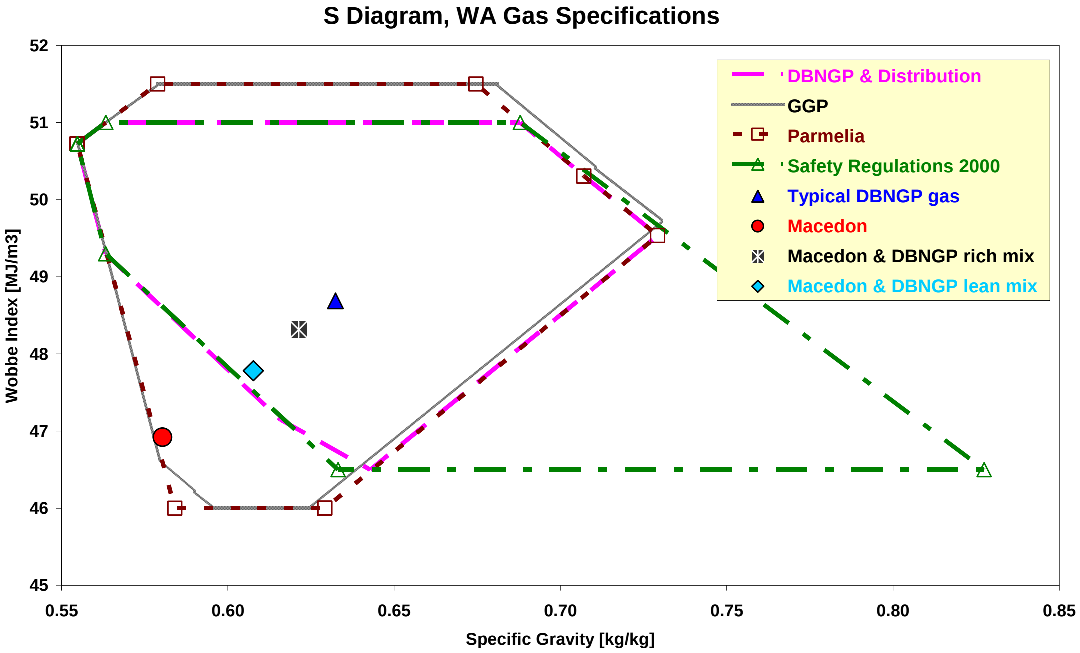
Gas from the Tubridgi field was delivered to the DBNGP system despite that it was outside of the regulated envelope. A “mixing space” created by upstream gases allowed this gas to be blended and safely delivered to the market. The gas from the Tubridgi field is now depleted.

The possibility of delivering Macedon gas to the DBNGP is hampered by the fact that its gas is outside of the existing DBNGP gas envelope. Paradoxically, Macedon gas would be allowed to enter the GGP or Parmelia systems without restrictions.

Figure 6 below provides a comparison of gas quality envelopes including that for the DBNGP, Parmelia, GGT, and the Western Australian specification set out in the *Gas Standards (Gas Supply and System Safety) Regulations.*

A typical DBNGP gas in future years[24] is also shown in the S Diagram (Figure 6 below).

**Figure 6, WA gas envelopes.**



DBNGP gas is located around the centre of the most restrictive envelope, thereby providing a substantial mixing space.

A modelling of a mixture of the existing rich DBNGP gas with the unprocessed Macedon gas indicates that it would be possible to safely blend a substantial gas quantity from the Macedon field without compromising any currently regulated limits of the DBNGP gas specification. This mixture of DBNGP gas and the unprocessed Macedon gas is shown in Figure 6 as “rich mix”.

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[24] Page 20 of “Review of Gas Specification For The Dampier to Bunbury Pipeline & Determination of an Appropriate Gas Composition for Design of Stage 5 Expansion”, M. J. Kimber Consultants Pty. Ltd. 22 February 2006.

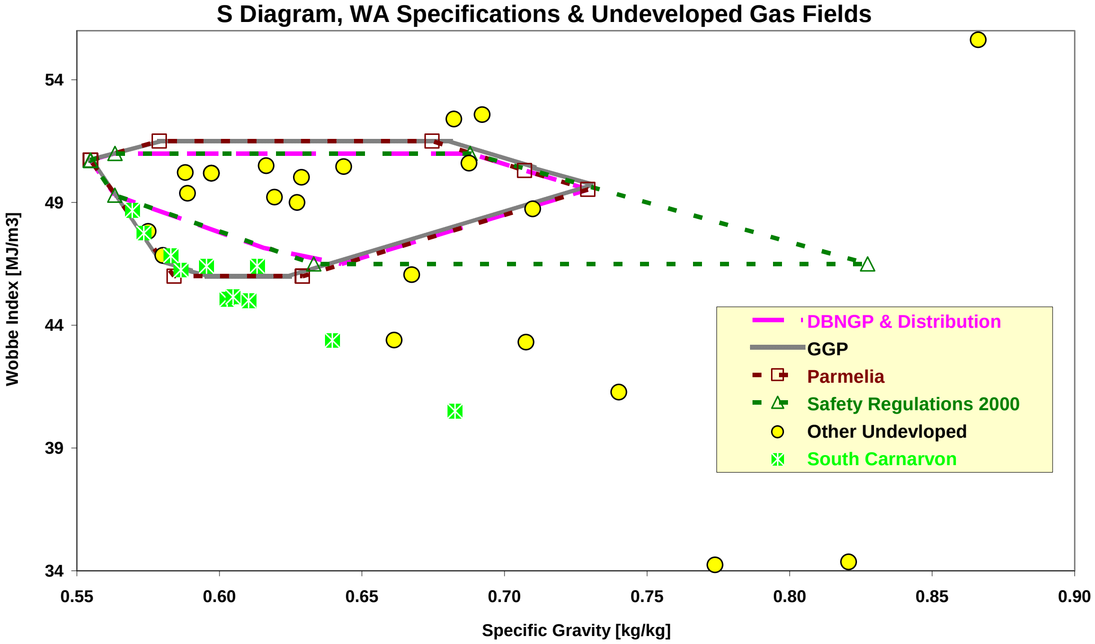
Further modelling shows that even if all LPG components were removed from the DBNGP upstream gas, the gas mixture (lean mixture), with a substantial portion of Macedon gas, would still be within the boundaries of the DBNGP gas specification due to a relatively high content of ethane (C2) in the upstream gas. Both rich and lean mixtures are shown in Figure 6 above.

There are several fields located in the South Carnarvon Basin that have a similar gas composition to Macedon gas. These other fields contain predominantly methane (C1), relatively high levels of nitrogen (N2) and low levels of carbon dioxide (CO2). These gases may be mixed and processed on shore in one processing plant creating a South Carnarvon gas hub. The gas from this hub could be delivered to the DBNGP system by one dedicated pipeline. The creation of the South Carnarvon hub would introduce the possibility for gases with similar compositions to Macedon gas and from small or marginal fields to supply gas to the Western Australian market in competition with gas from other gas fields.

There are also several gas field including Gorgon, Reindeer, Scarborough and Pluto that, in the near future, may be used to produce gas for both the LNG and the domestic markets.

Gas qualities from these fields, South Carnarvon Basin fields and other selected undeveloped fields are shown on the S Diagram in Figure 7 below.

**Figure 7, Undeveloped gas fields.**



The gases with a relatively higher level of heavier hydrocarbons have a high level of WI and SG. They are located at the upper and right hand sides of the S Diagram.

Gases with an increased level of inert components are characterised by a lower level of WI and a higher level of SG. These gases are located at the lower and right hand sides of the S Diagram.

# Management of Gas Exchangeability

There are several options to allow gases located outside the regulated specification to enter the gas market. These options include:

1) mixing and blending of gases;
2) gas processing;
3) broadening of gas specification; and
4) a combination of the above.

## *1. Mixing and blending of gases.*

Natural gases of different quality and composition can be mixed together at a point upstream of transmission systems to meet the gas specification. Gas suppliers that have access to several gas fields can use this method.

The mixing of a lean gas predominately consisting of methane, carbon dioxide and nitrogen with a rich gas that contains a relatively low methane level and high levels of other hydrocarbons can achieve a mixture that is located within the gas envelope. The exact location on the S Diagram of this mixed gas depends on the chemical composition and quantities of both gases.

Blending of gas occurs when a gas outside the specification enters a transmission system downstream of other gases and the upstream gas in the pipeline has a “mixing space”. This mixing space determines the quantity of a gas outside the specification that can be blended. The blended gas quantity has to follow variations in upstream gas quality and quantity.

Alternatively, the blending may occur outside the transmission system. The blending gas supplier may buy the gas from the upstream supplier. After mixing this gas with the gas that is outside the gas specification, the blended gas is redelivered into the system.

Both blending scenarios only marginally improve the reliability of the gas supply as the quantity of the gas being blended depends on the quantity of the upstream gases and their qualities. Any reduction in the mixing space of upstream gases would result in a quantity reduction in the blended gas.

The quantity of out of specification gas to be blended may also be affected by any variation in gas nominations; therefore blending is only practical where a relatively small quantity of out of specification gas is involved.

In addition, in the competitive gas market, the upstream gas supplier may decide to reduce the mixing space or impose prohibitive high charges for maintaining the mixing space.

Gas blending is a relatively low cost solution, however due to the competitive nature of the market it is rarely used.

## 2. Gas processing.

Generally all natural gas is treated and processed before entering transmission systems. This treatment includes removal of an excessive level of contaminants such as sulphur, hydrogen sulphide, oxygen and water. Gas processing includes the removal or reduction of carbon dioxide, nitrogen and hydrocarbons heavier than methane.

The cost associated with gas treatment and processing can be relatively high. The removal of heavier hydrocarbons or nitrogen reduction by using refrigeration, cryogenic processes or pressure swing methods is especially expensive. However, if volume of gas is sufficient, removal of LPG may be warranted as LPG usually attracts higher prices than natural gas.

Recently, the Western Australia Government gave preliminary approval for the development of the Gorgon gas fields on the condition that CO2 be removed from the gas and is re-injected into the rock structure under Barrow Island.[25] It is likely that partial removal of CO2 complemented by carbon sequestration may be a condition for the development of new gas fields that contain significant levels of CO2. Carbon sequestration further increases gas processing costs.

Some marginal gas fields and oil-associated gases may not have sufficient volume to justify the cost of processing. The mixing of gases from different fields before this mixed gas is processed may make gas processing economical.

Nitrogen or air injection may be used for treatment of rich gases with a high WI. The cost of air injection is relatively less than that of nitrogen injection (N2 blasting), as the continuous production of nitrogen is an energy intensive and costly process. Air injection is limited as the majority of jurisdictions restrict the level of oxygen in the gas. Some jurisdictions accept a relatively high level of nitrogen when the WI is maintained within an acceptable range.

When natural gas contains only methane and inert gases, the removal of the inert gases or the injection of heavier hydrocarbons (gas spiking) are the only methods that can be used to make this gas acceptable for jurisdictions that limit minimum HHV and/or minimum WI. The removal of nitrogen involves a cryogenic process and is relatively expensive and a drawback of "gas spiking" is the accessibility of a source of heavier hydrocarbons. As Macedon gas contains mainly methane and nitrogen, the owner of this field is facing potentially high processing costs.

Gas processing is the most effective method used to modify gas parameters. As the cost of gas processing is relatively high, it has limited application for gases from small and marginal fields or from gas that is associated with the production of oil.

## 3. Broadening of gas specification.

The cost of processing gas and the economics of gas supply are directly related to the limits imposed by the gas quality specification. The gas quality specification also impacts on competition in both upstream and downstream markets. Options for the development of a uniform broad gas quality specification are examined in the following sections.

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[25] WA Government Portfolio: Climate Change, Environment. Environmental and Climate Change Minister Statement Release at 7 September 2007

# Australian Standard and WA gas specifications.

The three main natural gas transmission and distribution systems that supply the south of the State are covered by different gas specification envelopes.

The most restrictive gas specification envelope covers both the DBNGP gas transmission system and the Mid West and South West gas distribution systems. This specification applies to around 80% of gas transported in Western Australia.

The current limited gas supply in Western Australia with correspondingly high prices focuses attention on gas specifications and options for broadening the specifications.

The creation of a less restrictive gas specification that would apply to all transmission and distribution systems supplying residential users is essential for the establishment of an effective and competitive gas market.

A factor hindering the broadening of the current DBNGP gas specification envelope continues to be the existence of “old” gas appliances on the distribution systems. A comprehensive removal and modification program is understood to be necessary before modifications of the currently regulated specification limits are implemented.

One of the options to broaden the Western Australian specifications is to simply accept the national gas specification prescribed by the Australian Standard AS 4564.

The explanatory notes of the national standards state the following:

- *“Higher Heating Value: It is expected that for all practical gases available, or likely to be available commercially, higher heating values would be in the range of 37 to 42MJ/m3.”*
- *“Relative density: It is expected that for all practical gases available, or likely to be available commercially, higher heating values would be in the range of 0.55 to 0.7.”*

Table 4 shows the main parameters of the national gas specification and the limitations implied by the explanatory notes;

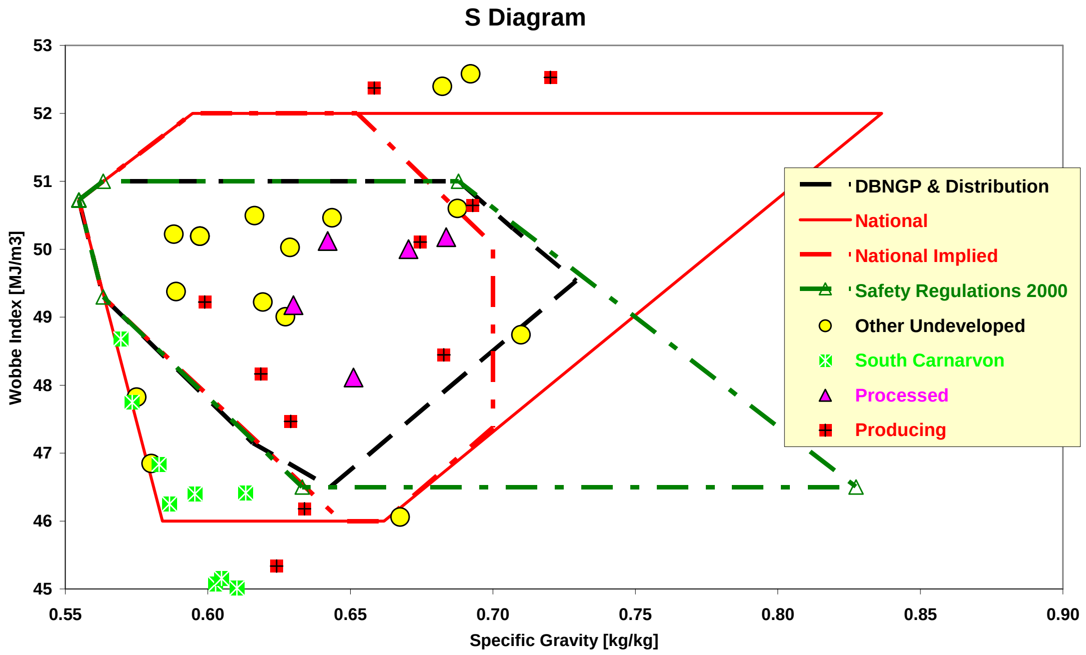
**Table 4**

| Characteristics and components | Unit | DBNGP AA | Safety Reg. 2000 | National AS 4564 | Implied National |
|---|---|---|---|---|---|
| Maximum Wobbe Index | MJ/m3 | 46.5 | 46.5 | 46.0 | 46.0 |
| Minimum Wobbe Index | MJ/m3 | 51.0 | 51.0 | 52.0 | 52.0 |
| Maximum Higher Heating Vale | MJ/m3 | 37.0 | 37.0 | - | 37.0 |
| Minimum Higher Heating Value | MJ/m3 | 42.3 | 42.3 | - | 42.0 |
| Maximum Relative Density | kg/kg | - | - | - | 0.70 |
| Minimum Relative Density | kg/kg | - | - | - | 0.55 |
| Maximum Total CO2 | Mole% | 4.0 | - | - | - |
| Maximum Total Inerts | Mole% | 7.0 | - | 7.0 | 7.0 |

For illustrative purpose, the regulated limits of the DBNGP and WA Safety Regulations 2000 are also shown.

Figure 8 below illustrates the gas envelopes of DBNGP, WA Safety Regulations 2000 and national specifications. The envelope delineated by the limits stated in the explanatory notes (implied envelope) is also shown.

**Figure 8, Gas envelopes and selected gas fields.**



For illustrative purposes, gas parameters of some of the Western Australian gas fields are also shown. The existence of several gases from current and potential gas fields that are located outside the limits of the implied national specification highlights the contradiction in the explanatory notes quoted above.

It is interesting to note that the envelopes of the national standard and the Safety Regulations 2000 cover different and in part, mutually exclusive areas of exchangeable gases.

The lack of any restrictions imposed by the national envelope of gases containing a high level of heavy hydrocarbons is the biggest concern. Many jurisdictions introduce other physical and/or chemical parameter limits eliminating the entry of gases containing high levels of heavy hydrocarbons into the systems.

A natural gas containing a high level of heavy hydrocarbons and a high level of inert gases may have a WI within an acceptable range, however, the use of such gas in reciprocating engines or gas turbines would increase the risk of auto ignition or knock-backs.

In addition, the combustion of gas containing a high level of inert gases and heavier hydrocarbons may also increase the risk of excessive soot deposition and carbon monoxide generation. Some jurisdictions address these potentially unsafe conditions by regulating the maximum level of heavier hydrocarbons.[26]

The level of CO2 is only restricted in the national specification by the limit placed on inert gases. Consequently, under the national gas specification, 7% CO2 would be permitted. In the past, some Western Australian industries have expressed concern about potential negative impacts of a high CO2 level on processes using natural gas as a feedstock.

There is also an issue of the impact of CO2 on the environment. A gas containing 4.0Mole% CO2 adds around 1.8 tones of CO2 per TJ over and above that generated during combustion. If CO2 increased to 7.0Mole%, total CO2 would increase by around 3.2 tones of CO2 per TJ.

The current volume of gas transported in Western Australia is around 1,000TJ/day. If the limit for CO2 were increased from the currently regulated level of 4.0% to the national allowable level of 7.0%, the additional amount of CO2 released to the atmosphere could increase by up to1,400 tonnes per day.

The CO2 limit regulated in the majority of developed countries is less than 3.0%.

The introduction of new gas sources combined with a broadening the gas specification, especially the WI limits, impact on the capacity of gas transmission systems if the WI of the gas mixture in a pipeline varies from the design WI value.

Specifically, any reduction of the current low WI limit of 46.5MJ/m3 could potentially reduce the capacity of the system and may increase the operating cost. Inversely, any increase of WI above the current high WI limit of 51.0MJ/m3 could potentially result in a proportional increase in the pipeline capacity and may reduce the operating cost.

One possible solution is to apply a WI correction factor to the reference tariff. As there is a linear relationship between the pipeline capacity and the Wobbe Index, as described in the previous paragraphs of this paper, this WI correction factor can be a ratio between the pipeline design WI and average value of shipper's gas WI. The applicable tariffs could be determined by using the following equation;

$$T_A = T_R * \frac{DesignWI}{AvgWI}$$

$$where$$

$$T_A \text{ - Applicable Tariff}$$

$$T_r \text{ - Reference Tariff}$$

$$AvgWI \text{ - Shippers Average WI}$$

$$DesignWI \text{ - Pipeline Design WI}$$

This factor would increase reference tariffs for shippers transporting gas with the WI lower than the WI used in the pipeline design and it would reduce reference tariffs for shippers transporting gas with the WI in excess of the design value.

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[26] "white Paper on Natural Gas Interchangeability and non-combustion end use", USA, NGC+ Interchangeability Working Group, 28 February 2005, Interim Guidelines.

Another solution is for the shipper transporting gas with a lower WI than the one used in the pipeline design to make a capital contribution to compensate for the capacity loss or to pay a surcharge to compensate for any increase in the operating cost.

The majority of gases entering Western Australia gas transmission systems are processed. An increased safety risk may be created in the situation when one of the processing plants is not fully functional and the processed gas delivered to the market is within the extremity of the national gas specification. In this situation, a slug[27] of the gas with high levels of heavier hydrocarbons would enter the gas market and create potentially unsafe combustion conditions.

It is possible to create an optimum gas envelope with its limits between the national specification, the limits implied by the explanatory notes and the WA Safety Regulations 2000 limits without compromising the safety and efficiency of gas usage in the residential and industrial appliances.

## Modifications of WA gas specifications.

The following sections of this paper concentrate on the gas specification currently applicable to the DBNGP, the Western Australian gas distribution systems and the WA Safety Specification 2000.

The DBNGP specification could be extended by modifications of discrete elements of the gas specification. Each of these gas specification elements refer to specific gas parameters and a distinctive area of the gas specification envelope.

The speed of progress from the current gas envelope to a broader specification would need to be synchronised with a well defined and comprehensive program of testing and removal or modification of unsuitable (older type) appliances.

Such a new specification, if applied to all regulated and unregulated natural gas transmission and distribution systems in Western Australia, would remove the currently existing artificial barriers that result from the existence of the different specifications in the State.

In considering the issues raised, there is also a case for reviewing the national specification described in the Australian Standard, AS4564-2005. However, any review of gas specification limits in Western Australia is not contingent on a review of the national gas specification.

The following discussion gives consideration to several modifications that might be implemented to achieve an optimal gas quality envelope capable of application at both the State and national level. Optimality in this sense envisages the broadest possible gas quality envelope without compromising safety, technical or economic efficiency.

### *1st Element. Reduction or removal of minimum HHV limit.*

The existence of a minimum HHV limit excludes any natural gases that contain predominantly methane associated with a high level of the inert gases, specifically nitrogen. As discussed above, the cost of processing such gas can be prohibitive.

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[27] When a relatively large quantity of a gas enters a pipeline system downstream of other gases, it mixes with the other gasses at the point of entry, however, this mixture travels along the line without further mixing.

Gases with a WI of 46.5MJ/m3 do not exist below a HHV level of 35.43MJ/m3. The reduction of the minimum HHV limit to 35.4MJ/m3 and retention of the minimum WI of 46.5MJ/m3 effectively removes HHV as a limiting factor of the gas quality envelope.

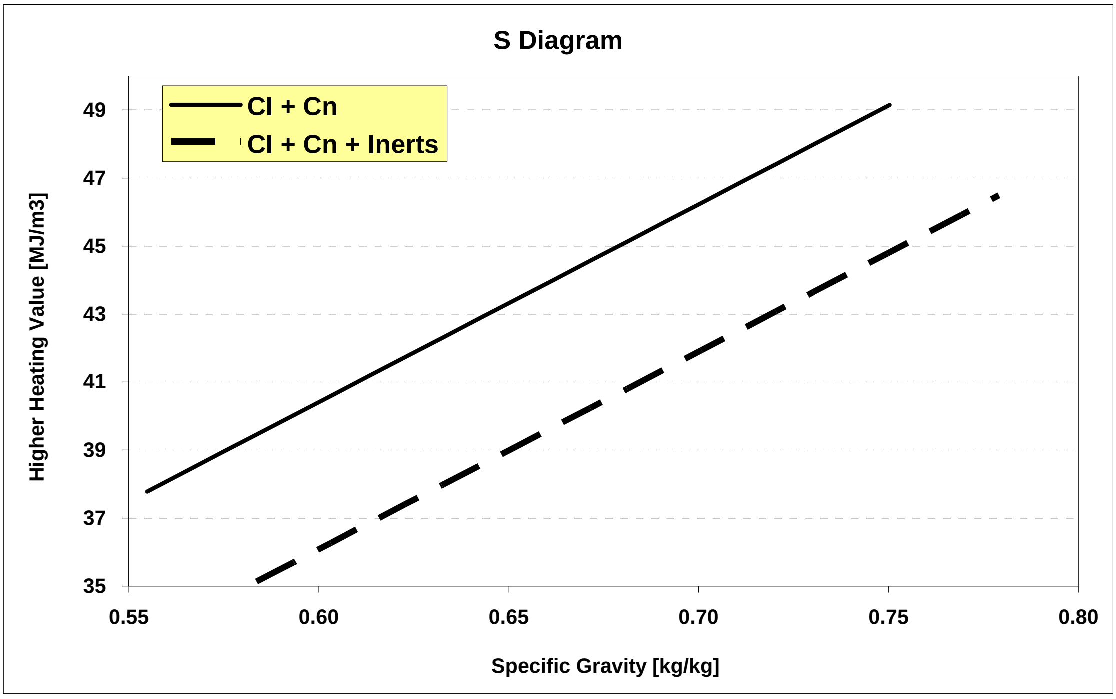
Gases with a WI of 46.0MJ/m3 do not exist below a HHV level of 35.13MJ/m3. The reduction of the minimum HHV limit to 35.1MJ/m3 and retention of the minimum WI of 46.0MJ/m3 effectively removes HHV as a limiting factor of the gas quality envelope.

In these circumstances, the minimum HHV limit could simply be removed.

## *2nd Element. Replacement of the maximum HHV limit with a maximum SG limit.*

The Higher Heating Value and Specific Gravity increase with increased levels of heavier hydrocarbons. Consequently, SG is directly proportional to HHV. This linear relationship is illustrated in Figure 9. below.

**Figure 9, Higher Heating Value versus Specific Gravity.**



The solid line represents a gas containing only hydrocarbons. Addition of inert gases shifts this line parallel and to the right (dotted line).

Sooting is generally related to a higher level of heavier hydrocarbon content. The purpose of the maximum HHV limit is to restrict the level of heavier hydrocarbons. It is noted that the trend in other jurisdictions is toward substituting the maximum HHV limit with a maximum SG limit. The use of a SG limit complements the maximum WI limit.

A practical and pragmatic alternative to the use of a HHV limit for restricting the level of heavier hydrocarbons, therefore, is to introduce a maximum SG limit of 0.73kg/kg.

## 3rd Element. Replacement of the maximum N2 level with the maximum SG level.

Specific Gravity increases with the level of inert gases. Consequently, a SG limit can be used as a restriction on gases containing a high level of inert gases. The maximum and minimum limits of the Wobbe Index combine with the maximum SG limit to address sooting, incomplete combustion, flame lifting and flashback phenomena.

The use of a SG limit therefore allows for both the maximum HHV and nitrogen limits to be removed.

It is noted that the maximum WI of 54.0MJ/m3, minimum WI 46.0MJ/m3 and maximum SG of 0.8 are the only limits applicable to natural gas systems in New Zealand. The proposed United European transitional gas specification has four limits; maximum WI of 54MJ/m3, minimum WI of 47.0MJ/m3, maximum SG of 0.7 and maximum CO2 of 2.5Mole%.

The CO2 limit in the Australian standard (7.0%) and the Western Australian gas specifications (3.6% to 4.0%) have the highest limit than any other developed country. Considering the environmental impact of carbon dioxide (CO2) emission and a relatively low cost of CO2 removal, a consideration might be given to limit CO2 level to around 2.0Mole% to 3.0Mole%.

Following the oversees trend, a CO2 limit of 2.5Mole% could be adopted. If the CO2 limit were reduced by 1.5Mole%, the resultant reduction in the CO2 (if sequestrated) released to the atmosphere in Western Australia would be around 300,000 tonnes per annum.

A practical and pragmatic approach in Western Australia would be to retain the current CO2 limit of 4.0Mole% and replace the existing 7 Mole % NO2, limit with a SG limit of 0.73kg/kg.

## 4th Element. Increments of maximum WI limit from 51.0MJ/m3 to 52.0MJ/m3.

The high limit of the Wobbe Index is to address incomplete combustion and sooting.

One of the test gases prescribed by Australian Standards that is designed to test natural gas appliances for suitability to use gases with high Wobbe Indices has a WI of 55.0MJ/m3. This represents a safety margin of around 5.8% for gas with WI of 52MJ/m3.

Experiences in other countries, and especially in the European Union (EU), indicate that modern gas appliances in the majority of the EU can safely accept gases with a WI range of between 47.0MJ/m3 to 54.0MJ/m3.[28]

The test pressure for the EU appliances (except Netherland) is 20mbar and the WI of the test gas is 45.66MJ/m3 to 54.76MJ/m3. These testing parameters vary from those testing parameters used in Australia. Therefore, the proposed European WI range can only be taken as a guide when compared with Australian test conditions. The proposed high WI safety margin for European appliances is around 1.5%

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[28] Gas Appliances Directive 90/396/CEE or ”GAD”

If the test results of appliances with a test gas designed to test the extremity of Element 4 are successful, it may be possible to extend the WI limit to 52.0MJ/m3 or some value above this limit

## *Step 5. Reduction of minimum WI limit from 46.5MJ/m3 to 46.0MJ/m3.*

The minimum limit of the Wobbe Index is to address flame lifting problems.

It is understood that there are only a limited number of developed countries that allow the WI limit below 47.0MJ/m3. The Western Australian and New Zealand gas specifications have the low limit of WI below this value. Currently, the minimum WI limit in Western Australia of 46.5MJ/m3 is regulated by *Gas Standards (Gas Supply and System Safety) Regulations 2000*.

Although the national gas specification applies a minimum WI of 46.0 MJ/m3 and there have been proposals to move the minimum WI to this limit in Western Australia, any reduction in the minimum level of the WI from 46.5MJ/m3 to 46.0MJ/m3 should be contingent on appliance testing demonstrating that such a reduction in the WI is safe.

Recognising the impact that low WI gas has on pipeline capacity, consideration to the introduction of a WI correction factor or any other mechanism that would apply to regulated reference tariffs would seem warranted.

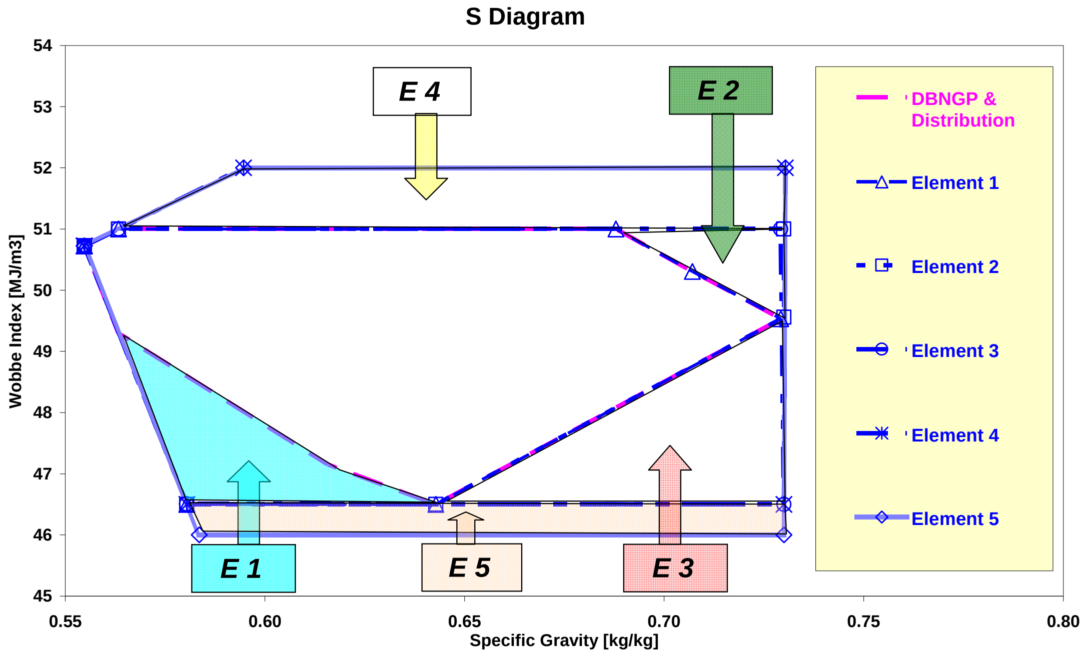
Table 5 below summarises each of the elements discussed above. The resulting gas quality envelope aims at being as broad as is reasonably possible without compromising safety, technical or economic efficiency. The specification is also as simple as possible, delineating the gas quality envelope on the basis of only three parameters and four limits (minimum and maximum WI, maximum CO2 and maximum SG).

**Table 5**

| Parameter | Unit | DBNGP | 1st Element | 2nd Element | 3rd Element | 4th Element | 5th Element |
|---|---|---|---|---|---|---|---|
| **Min HHV** | MJ/m3 | 37.0 | - | - | - | - | - |
| **Max HHV** | MJ/m3 | 42.3 | 42.3 | - | - | - | - |
| **Min WI** | MJ/m3 | 46.5 | 46.5 | 46.5 | 46.5 | 46.5 | 46.0 |
| **Max WI** | MJ/m3 | 51.0 | 51.0 | 51.0 | 51.0 | 52.0 | 52.0 |
| **Max CO2** | Mole% | 4.0 | 4.0 | 4.0 | 4.0/2.5 | 4.0/2.5 | 4.0/2.5 |
| **Max Inerts** | Mole% | 7.0 | 7.0 | 7.0 | - | - | - |
| **Max SG** | kg/kg | - | - | 0.73 | 0.73 | 0.73 | 0.73 |

The gas quality envelopes specified in Table 5 are illustrated on the S Diagram in Figure 10 below.

**Figure 10, Gas specification modification steps.**



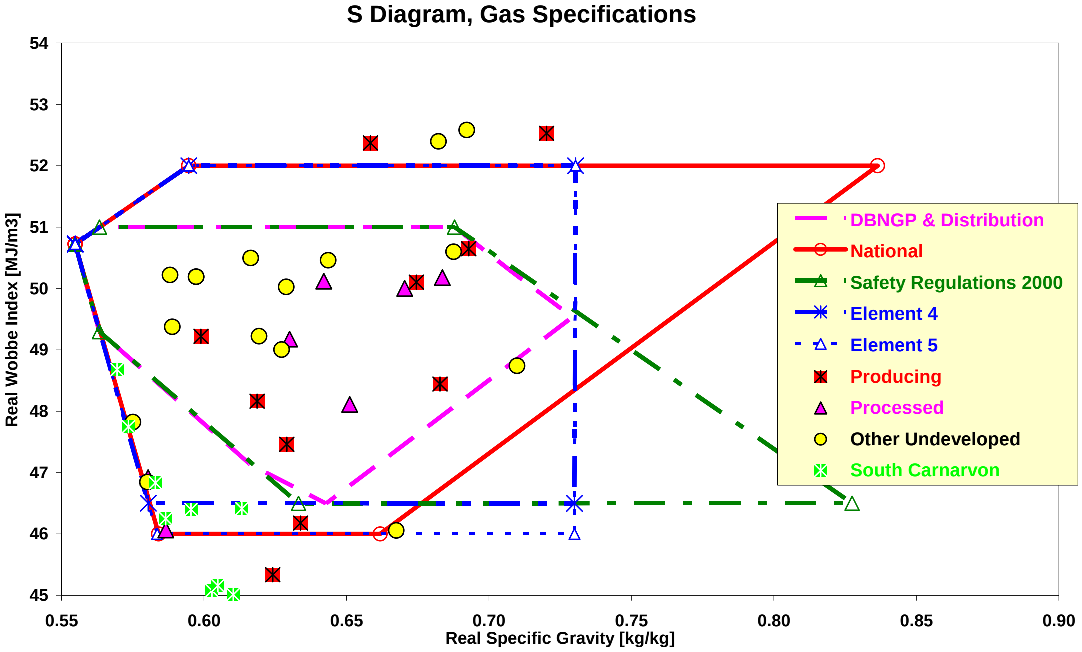
If the gas quality specification derived in 1st Element of Table 5 were adopted then gases with the characteristics of Macedon gas would have access to the DBNGP system and the Perth distribution network.

It should be noted that the implementation of Element 1 to Element 4 of the modifications set out in Table 5 above may have a negligible impact on the capacity of transmission pipelines as the minimum WI is not altered.

Element 5 would remain contingent on meeting safety requirements, the implementation of a mechanism to compensate gas pipelines for the reduction of deign pipeline capacities and providing a net economic benefit taking the impact of lowering the WI from 46.5MJ/m3 to 46.0MJ/m3 into account.

In summary, Figure 11 below provides a comparison of gas quality envelopes including the national specification, that for the DBNGP, the Western Australian specification set out in the *Gas Standards (Gas Supply and System Safety) Regulations 2000* and the 5th Element modification.

**Figure 11, Comparison of gas envelopes.**



The above S Diagram also shows the gas parameters of existing producing gas fields and selected non-producing fields.

The cost of processing gas from some existing and non-producing fields may be eliminated or substantially reduced after implementation of the proposed modified gas envelope. The cost of the gas processing from other fields that are located outside the final gas envelope may also be reduced.

Introduction of the SG limit of 0.73, reduction of CO2 limit to 2.5% and the removal of the limit of total inert gases, would make acceptable natural gases with the nitrogen level up to around 12Mole% as long as other limits are met.

The proposed 4th Element gas envelope is considered to represent a well-balanced solution that addresses conflicting requirements of participants in the gas market including gas producers, transporters, end users and the manufacturers of gas appliances without compromising efficiency or safety.

However, if safety requirements are satisfied and a suitable and transparent mechanism addressing the impact of variations in the WI on pipeline capacity is implemented, the 5th Element modification, involving a reduction in the lower WI limit to 46.0MJ/m3, may be given consideration.

To assess the suitability of modified gas envelops, a set of test gases design to test the extremity of the area covered by these envelops should be used. Test gases are further discussed in the Appendix 1.

# Conclusions.

Following are a number of conclusions that may be drawn from the analysis presented in this paper:

- the gas specification applicable to the pipeline systems supplying around 80% of Western Australia's gas needs (DBNGP and Western Australian distribution systems) is the most restrictive of those applying in this State;
- any broadening of this restrictive gas specification could only take place after a comprehensive program of identification and testing of "old" appliances together with a program to replace or modify such appliances where necessary;
- consideration of any reduction in the WI from 46.5MJ/m3 to 46.0MJ/m3 could be conditional on the introduction of a transparent compensation mechanism for the WI impact on pipeline capacity;
- there is merit in considering a review of the *Gas Standards (Gas Supply and System Safety) Regulations 2000 and the so called national gas quality specification*;
- that the introduction of changes to the current gas specifications would be likely to be best done in synchronisation with the appliances replacement and modification program;
- the final specification would be suitable for all new entries to the gas market including gas fields, pipelines and appliances;
- that the S Diagram serves as a useful way in which to illustrate and analyse gas exchangeability; and
- a review of test gases for domestic appliances should be initiated.

A review of gas quality specifications as discussed in this paper are expected to have immediate and lasting benefits at both a national and State level by reducing or eliminating gas processing costs whilst meeting safety requirements and providing net economic benefits.

These benefits would include encouraging the development of otherwise marginal gas fields, increased utilisation of gas from oil-associated fields and by the promotion of direct gas to gas competition.

Michael Mieczyslaw Soltyk

MEngSc (Electrical Engineering)

# Appendix 1, Test gases

All gas appliances used in Australia have to satisfy the testing requirements prescribed by several Australian Standards. The testing of each type of the gas appliances is governed by the specific Australian Standard.

The test gases are the same for all gas appliances. There are four test gases specified by Australian Standards[29] for testing appliances that are designed to use natural gas as a fuel. The following Table 6 shows the compositions and parameters of these gases.

**Table 6**

| Parameter | Test Gas N | Test Gas Na | Test Gas Nb | Test Gas Nc |
|---|---|---|---|---|
| Methane [mole%] | 97.5 | 86 | 87 | 90 |
| Propane [Mole%] | 1 | 14 | | |
| Nitrogen [Mole%] | 1.5 | | | 10 |
| Hydrogen [Mole%] | | | 13 | |
| Wobbe Index [MJ/m3] | 50.0 | 55.0 | 49.1 | 44.0 |
| Higher Heating Value [MJ/m3] | 37.8 | 45.7 | 34.4 | 34.0 |
| Specific Gravity [kg/kg] | 0.571 | 0.692 | 0.492 | 0.596 |

In support of any move toward a broadened gas quality envelope, test gases need to be specified for testing the extremity of each area of the gas envelope. The testing gases should contain a combination of the following four naturally occurring compounds:

- methane (C1H4);
- propane (C3H8);
- carbon dioxide (CO2); and
- nitrogen (N2).

Test gases should also be located outside the tested areas by a reasonable margin. As measuring devices used in testing gas quality are very accurate, small margins of extreme values of gas parameters should be sufficient to provide a safety margin for any variation in gas quality.

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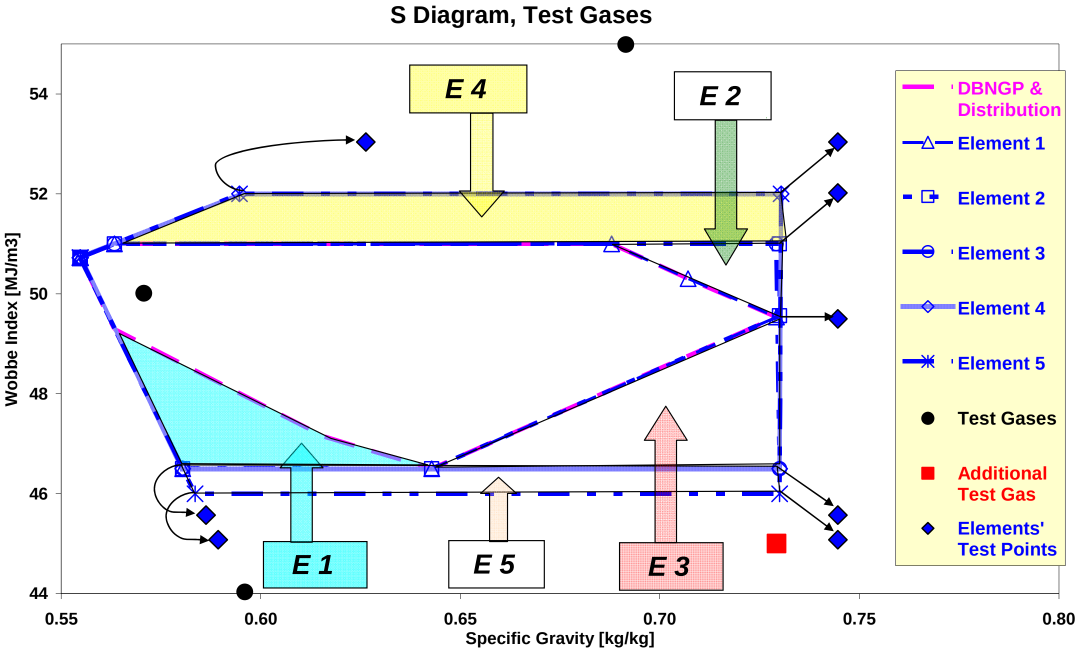
[29] AS 4553-2000, AS 4551-200 and AS 4552-2005

Each of the modification elements set out in Table 5 should be tested with one or several gases. The selection of the number of test point gases for each element should reflect the number of gas parameters to be tested.

The selected gas appliances should be tested with all test gases. Results from all tests should be used as one of the factors when developing a time schedule to implement changes to gas specifications. These changes of the gas specifications should be synchronised with the appliance replacement and modification program.

The proposed modification elements the location of test gases (except Nb) and the location of proposed test points on the S Diagram are shown in Figure 12 below.

**Figure 12, Test gases.**



Test gases specified by the Australian Standard are well placed to test the extremity of a “rich” and “lean” gas regions. The lean test gas (Nc) contains only methane and nitrogen and the rich test gas (Na) contains only methane and propane.

The N test gas is located around the middle of the Wobbe Index range and has low specific gravity. The Nb test gas contains hydrogen and is not shown in the S Diagram above.

It would be desirable to test gas appliances with a test gas having a low level of WI and a high level of SG. This gas is also shown if Figure 12.

It is also noted that margins between the parameters of test gases and the extremities of the national gas specification are at least twice than that in other developed countries. This creates a bigger safety buffer especially for gas appliances that are not frequently maintained. However, it is most likely, that this will impose a higher cost of appliance production.

It may be beneficial to define a new set of test gases with a lower margin than that of the current test gases.