Business Case – Capital Expenditure

Evaluating and mitigating hydrogen safety and integrity risks on the VTS

Business Case Number 200

1 Project Approvals

BUSINESS CASE – PROJECT APPROVALS	
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2 Project Overview

BUSINESS CASE – PROJECT OVERVIEW	
Description of Issue/Project	This project is proposed to quantify the risks to safety and integrity of the existing pipeline material and facilities caused by the introduction of hydrogen, and identify any actions required to mitigate the risks for the VTS network. • Amendments to the National Gas Law are being expedited so that hydrogen blends, and other renewable gas blends are brought within the national energy regulatory framework. This is essentially a change in product specification driven by policy. • When a steel pipeline, like the existing VTS network, is exposed to hydrogen, hydrogen is absorbed into the steel and deleteriously affects the material properties. This is known as hydrogen embrittlement. In particular, the ductility, toughness and fatigue life of the steel is deteriorated. This deterioration of steel properties has the potential to impact the safety and integrity of the pipeline system. • The VTS is a complex interconnected network, and there is a possibility that hydrogen injected either upstream or downstream by another gas infrastructure owner/operator could make its way into the VTS network. • If hydrogen enters the VTS network without completion of the proposed technical assessments, there will be an unknown impact on the integrity of the pipeline which may lead to premature degradation or failure of pipeline or facilities elements. This could ultimately lead to health and safety risks for the public, customers and operators / maintainers of the equipment. APA is required under Australian Standard AS2885 to ensure risks are as low as reasonably practicable (ALARP) for members of the public, our customers and our staff. • Despite the deterioration of material properties, emerging knowledge (from International and Australian projects) has identified that, based on a detailed technical assessment of the pipeline, the risks to safety and integrity could be sufficiently mitigated to allow high pressure transmission pipelines to carry hydrogen, thus facilitating the changes in the National Gas Law. • This proposed project will provide sufficient data to quantify the impacts of hydrogen embrittlement on the VTS network, any changes required to current operating parameters to mitigate safety and integrity risks, and any upgrades required for pipeline facilities associated with safety, integrity, and compliance.

Options Considered	The following options have been considered: 1. Option 1: Do Nothing 2. Option 2: Technical assessment of pipeline, including materials testing and facilities screening
Estimated Cost	$ 37,861,536
Consistency with the National Gas Rules (NGR)	The proposed expenditure complies with the new capital expenditure criteria in Rule 79 of the NGR because: • it is necessary to maintain the safety of services and maintain the integrity of services (Rules 79(2)(c)(i) and (ii)); and • it is such as would be incurred by a prudent service provider acting efficiently, in accordance with accepted good industry practice, to achieve the lowest sustainable cost of providing services (Rule 79(1)(a)).
Stakeholder Engagement	• We have sought feedback from customers through APA's VTS AA Roundtable sessions, as well as stand-alone hydrogen information sessions. • Feedback from the VTS stakeholder roundtables is generally accepting of the need to complete an assessment of hydrogen-compatibility to support the transition of the gas network in a decarbonised future. APA understands that this support is underpinned by a desire to maintain system security, and to optimise cost of supply of energy across both the gas and electricity networks. • There is recognition that significant work needs to be done to better understand the viability of repurposing the existing natural gas transmission network for hydrogen service, and that there is a genuine urgency to commence the work to support decarbonisation efforts. • The primary concern raised during the stakeholder consultation process was how the technical assessment would be funded and the impact to consumer tariffs. APA's tariff modelling estimates that the bill impact of this assessment is ~$2c/GJ which equates to approximately $1.10 per year for domestic customers, and approximately $10 per year for business customers[1].

3 Background and Project Need

The Victorian Government has committed to a target of net zero greenhouse gas emissions by 2050, plus an interim target for emissions to reduce 45–50% below 2005 levels by the end of 2030. The energy sector is identified as the largest source of Victoria's emissions; primarily from fossil fuels burned for electricity generation (mainly coal) and combusted directly by industries, businesses, and households (mainly natural gas)[2].

In 2021, the Victorian Government released its Gas Substitution Roadmap[3] for consultation. The Roadmap presents several scenarios that explore how the gas sector might reach net zero emissions and identifies that electrification, hydrogen and biogas will all likely play a role in the decarbonisation of gas infrastructure.

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[1] This tariff modelling assumes depreciation over a 5-year period. If the assessment can be depreciated over the 30-year life of the asset, then the bill impact to customers will be reduced

[2] The State of Victoria Department of Environment, Land, Water and Planning, "Victoria's Climate Change Strategy: Economic Analysis", May 2021 <https://www.climatechange.vic.gov.au/__data/assets/pdf_file/0023/521357/Victorias-Climate-Change-Strategy-Economic-Analysis.pdf>

[3] The State of Victoria Department of Environment, Land, Water and Planning, "Victoria's Gas Substitution Roadmap: Consultation Paper", June 2021 <Victorias_Gas_Substitution_Roadmap_Consultation_Paper.pdf (amazonaws.com)>

Decarbonising gas infrastructure will not be without its challenges. In 2019 the Victorian gas transmission and distribution network delivered 64,722GWh[4] of energy, compared with 41,480GWh[5] supplied by the electricity network. Table 1 compares the two systems in terms of maximum demand.

Table 1: Victorian 2019 Maximum Electricity and Gas Demand Expressed in GW

2019	Winter	Summer
Electricity - Maximum demand	7.6GW	8.7GW
Gas – Forecast hourly peak day demand in MW	20.8GW	7.1GW

The Australian Energy Market Commission (AEMC) announced on 23 September 2021[6] that Energy Ministers have asked the AEMC to review the National Gas Rules and National Energy Retail Rules to determine what changes are necessary to include low-level hydrogen blends and renewable gases in the frameworks.

On 21 October 2021 the AEMC initiated a rule change process for the National Gas Rules applying to the Victorian Declared Wholesale Gas Market (DWGM). This will assess a request made by the Victorian Minister for Energy, Environment and Climate Change that seeks to enable that market to recognise distribution connected facilities. These facilities may include hydrogen and renewable gas facilities as well as others such as storage.

In addition, jurisdictional officials will start a related review to identify amendments for the National Gas Law and National Energy Retail Law. The Australian Energy Market Operator (AEMO) will also carry out a review of the relevant gas market procedures to make amendments that will support the use of low-level hydrogen blends and renewable gases.

Victoria's journey to decarbonise the gas network is in its early stages, and there remains a significant number of unknowns including: scale, speed, and cost of electrification; the economics of hydrogen and how quickly the technology cost curve will come down; and the pace of uptake and scalability for other natural gas alternatives such as bio-methane. There is also uncertainty with regards to public perception and the willingness of customers to transition to hydrogen gas. Pilot projects in Australia and overseas are beginning to engage with consumers and build customer confidence in hydrogen as an alternative to natural gas. The case study below describes one community engagement project being delivered in the UK with Government support.

Case Study: UK hydrogen homes pilot

In July 2021, two semi-detached homes with appliances fueled entirely by hydrogen opened to the public. The homes have been built in a partnership between UK gas distributors Cadent, Northern Gas Networks (NGN) and the UK Government.

The hydrogen homes allow members of the public to interact with a range of hydrogen appliances including boilers, hobs, cookers, fires, and a barbecue. The hydrogen homes are intended to be in operation for three-years but could be extended up to 10 years.

Although not intended to be habitable, the homes provide an opportunity for residential customers to provide feedback and gain an appreciation for renewable gas alternatives of the future.

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[4] Includes transmission and distribution. Source: Australian Energy Market Operator, "2020 Victorian Gas Planning Report – Update", March 2020, converted into GWh

[5] TNSP operational performance data 2006-2019 extracted from: Australian Energy Regulator, "Electricity network performance report 2020", September 2020

[6] Direct quote: AEMC, "AEMC to review how rules can accommodate hydrogen and renewable gases", 23 September 2021 <AEMC to review how rules can accommodate hydrogen and renewable gases | AEMC>

Blending hydrogen into the existing natural gas pipeline network has been proposed as a means of transporting hydrogen, allowing storage and cost-efficient transmission of renewable energy to users as part of the transition to a low carbon economy.

The importance of blending in the gas network is highlighted by the NSW Standing Committee's State Development hydrogen report[7] which states that "gas blending helps to create an early market for hydrogen producers, demonstrate the benefits of hydrogen in decarbonisation, and can provide domestic offtake support to the emerging hydrogen export industry without significant additional investment in infrastructure".

Utilising the existing natural gas pipeline network provides several advantages for customers including:

1. Lower system costs - repurposing existing gas infrastructure for hydrogen is lower cost than building entirely new pipeline network or full electrification of the energy system[8].[9]
2. Maintaining high reliability and energy security – historically, Victorian gas customers experience an outage once every 36 years[10] compared with electricity network outages which occur frequently due to storms and system maintenance. Injecting hydrogen into the VTS supports diversity of energy sources and additional resilience for end users. Hydrogen projects that are positioned close to demand centers, producing hydrogen using a local electricity grid connection are at risk of intermittency caused by electricity network outages i.e., if there is an outage on the local electricity network the hydrogen will not be produced and will result in a hydrogen supply issue. Energy security can only be guaranteed by a diverse suite of energy supply arrangements. Diversity of energy sources supports resilience for end users.
3. Maintaining choice for customers – providing options means that customers have choices available to them; both electrification and low-carbon gas solutions. In addition, this provides a decarbonisation pathway for hard-to-abate end users, such as industrial processing facilities that require high temperature heat.

Distribution networks in Victoria are already investing in projects[11] and readying their network for hydrogen blending. It is therefore important that the transmission network is also prepared for hydrogen blending to ensure safe operation of the network connecting to these with hydrogen-ready distribution pipelines, and to ensure that Victorian customers continue to benefit from competitive supply from multiple hydrogen gas sources.

The current challenge with repurposing the existing high pressure (transmission) natural gas pipeline network is understanding what impact the introduction of hydrogen might have on the gas pipelines and their operation. This is a technical challenge that was identified in Australia's National Hydrogen Strategy, which noted that further evidence is required to confirm that hydrogen embrittlement issues can be safely addressed before blending of hydrogen in existing gas transmission networks can be supported.[12]

When a steel pipeline, like the existing VTS network, is exposed to high pressure hydrogen, hydrogen is absorbed into the steel and can degrade the material properties. This phenomenon is known as hydrogen embrittlement. In particular, the ductility, toughness and fatigue life of the steel is deteriorated when exposed to hydrogen. This

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[7] NSW Standing Committee on State Development, Report No 47 Development of a hydrogen industry in New South Wales, 30 September 2021 <https://www.parliament.nsw.gov.au/lcdocs/inquiries/2643/Report%20No%2047%20-%20State%20Development%20-%20Hydrogen%20industry.pdf>

[8] Australian Pipelines and Gas Association, "Gas Vision 2050", September 2020, <https://www.apga.org.au/sites/default/files/uploaded-content/website-content/gasinnovation_04.pdf>

[9] Clean Energy Finance Corporation, Australian hydrogen market study, 24 May 2021, <https://www.cefc.com.au/media/nkmljvkc/australian-hydrogen-market-study.pdf>

[10] Australian Energy Regulator, Gas distribution performance report, 2012, p13

[11] Australian Gas Infrastructure Group, "Hydrogen proposed for 40,000 customers in Albury-Wodonga", February 2021 <https://www.agig.com.au/media-release---hydrogen-proposal-in-albury-wodonga>

[12] Action 3.15 from: COAG Energy Council, "Australia's National Hydrogen Strategy", 2019 <https://www.industry.gov.au/sites/default/files/2019-11/australias-national-hydrogen-strategy.pdf>

deterioration of steel properties has the potential to impact the integrity and safe operation of the pipeline if it is not quantified and understood. [13]

Although there is significant work underway (both internationally and in Australia) to quantify the impacts of hydrogen embrittlement, it is recognised that the effects vary based on the underlying steel material properties. These material properties are unique to each pipeline and are determined based on the source of the steel, the manufacturing process, the construction methodology (including weld procedures, workmanship criteria, and bend forming), and operating conditions of the asset since entering service. The existing pipeline condition is also critical to understand; in-service defects (e.g., corrosion) which are typically deemed low risk for natural gas may pose a greater risk of failure in a hydrogen service environment.

International studies have reached a consensus that even at very low hydrogen blends the impact to the steel can be significant. The impact is related to hydrogen pressure rather than percentage blend of hydrogen, which is why embrittlement is a critical issue for transmission networks.

Figure 1 below shows the degradation of relative fracture resistance of X70 steel when exposed to hydrogen blends at 8500kPa, compared with natural gas[14]. It can be seen at very low blends (1%) the hydrogen partial pressure is sufficient to reduce fracture resistance. Similarly, Figure 2 shows the impact of hydrogen on fatigue resistance of various pipeline steels[15].

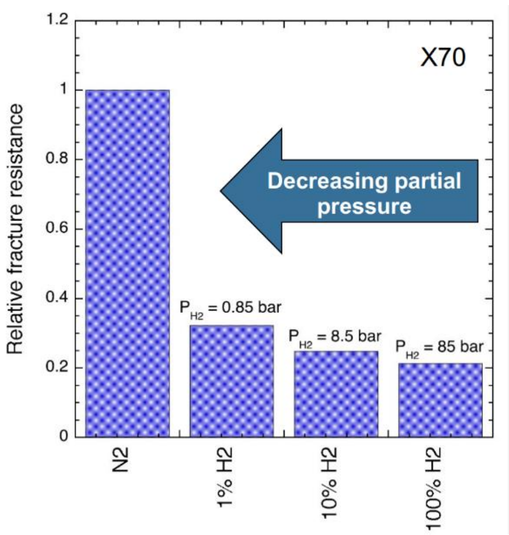

Figure 1

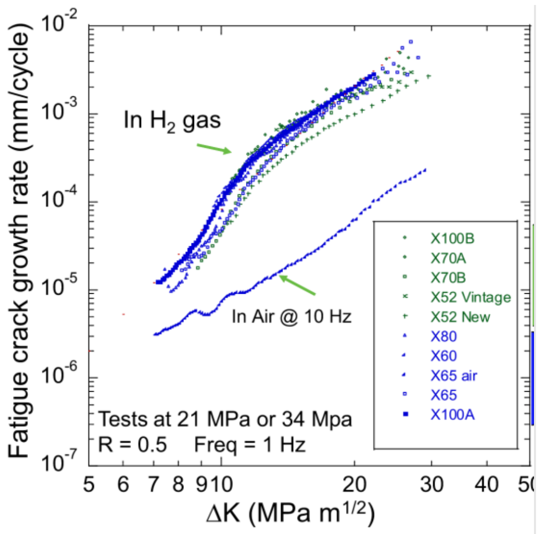

Figure 2

Given the likelihood of hydrogen blends being transported in the VTS, it is critical that APA as the VTS pipeline owner and operator undertakes technical assessments that enable quantification of the impacts of hydrogen embrittlement on the VTS. This work will also identify any changes that may be required to current pipeline operating parameters to

[13] Distribution networks are designed and operate under a different prescriptive standard AS4645 compared to the risk based with the transmission pipeline standard AS2885. The AS4645 design standard has inherent risk controls such as maximum design factor of 20% and 1050kPa MAOP has far greater capability to accommodate the change in ductility, toughness and fatigue life meaning that the pipes are not subject to rupture, and consequence such as heat rate release are controlled.

[14] Chris San Marchi, et al, "Materials Evaluation for Hydrogen Service", PRCI Hydrogen Storage Workshop 1 September 2021, SAND2021-10712PE

[15] Ronevich et al, "Assessment of Hydrogen Assisted Fatigue in Steel Pipeline", US Department of Energy, Office of Energy Efficiency & Renewable Energy, 27 September 2017, SAND2017-10181PE

mitigate any safety risks. This assessment must occur before *any* quantity of hydrogen gas enters the VTS network, either directly into the VTS or indirectly via another gas infrastructure owner/operator upstream or downstream.

Despite the deterioration of material properties, emerging knowledge (from international and Australian projects) has identified that, based on a detailed technical assessment of the pipeline, the risks to safety and integrity could be sufficiently mitigated to allow conversion of high-pressure transmission pipelines to be converted to hydrogen service.

One such Australian project is APA's Parmelia Gas Pipeline (PGP) conversion project. The Parmelia Gas Pipeline is an unregulated asset in Western Australia and APA has already committed significant investment into understanding the impacts of hydrogen embrittlement on this transmission pipeline. Our Parmelia Gas Pipeline conversion project[16] is the first high pressure pipeline in Australia that is undergoing detailed testing and analysis for conversion to hydrogen service. Through this project, APA has established an international advisory panel[17] including some of the world's most preeminent experts in the field of hydrogen materials testing and analysis. This advisory panel has provided guidance and validation on the project test plan, assessment methodology, and independent verification of results.

APA's Parmelia Gas Pipeline conversion project has been underway for over a year. Air testing results, engineering assessment and safety study have returned positive results for PGP hydrogen service conversion and indicate no service pressure de-rating will be required. Additional materials testing in hydrogen over the next twelve months will, we expect, further validate these conclusions, providing full confidence of the pipelines likely service performance, allowing detailed safety studies and conversion plans to be developed in consultation with the Western Australia safety regulator.

A technical paper describing the outcomes of the last twelve months of testing from our Parmelia Gas Pipeline conversion project in included as Appendix B.

While APA's Parmelia Gas Pipeline study is the first of its kind in Australia, it is not the first of its kind in the world. The following case study describes the successful conversion of a natural gas pipeline in the Netherlands to hydrogen, which has been in service since 2018. Two members of APA's international advisory panel were directly involved in this conversion project by Gasunie and are instrumental in the proposed conversion of the Netherland's national gas infrastructure to hydrogen[18].

Case Study: Gasunie – Netherlands' gas transmission network

In November 2018, Gasunie, the Netherlands' gas transmission operator, started transporting hydrogen along a 12km section of repurposed natural gas pipeline. The pipeline transports more than 4,000 tons of hydrogen per year for industrial purposes, saving over 10,000 tons of carbon emissions each year.

On 30 June 2021 the Netherlands Ministry of Economic Affairs and Climate Policy announced that it will commission Gasunie to develop the national infrastructure for the transport of hydrogen. The project, with an estimated investment of €1.5 billion, is scheduled for completion in 2027.

The new national hydrogen network will consist of 85% reused natural gas pipelines, resulting in costs four times lower than if entirely new pipelines were laid.

[16] APA Group, "APA set to unlock Australia's first hydrogen-ready transmission pipeline", 23 February 2021 <https://www.apa.com.au/news/media-statements/2021/apa-set-to-unlock-australias-first-hydrogen-ready-transmission-pipeline/>

[17] The international advisory panel includes European representatives who were directly involved in the conversion of a Gasunie pipeline from natural gas to hydrogen; an independent fracture mechanics expert who authored the pipeline defect assessment manual; and the leader of Sandia's Hydrogen Materials Lab and Hydrogen Compatibility Consortium in the USA.

[18] Gasunie, "Gasunie hydrogen pipeline from Dow to Yara brought into operation", 27 November 2018 <https://www.gasunie.nl/en/news/gasunie-hydrogen-pipeline-from-dow-to-yara-brought-into-operation>; Gasunie, "Dutch-German cooperation secures European future of hydrogen", 6 July 2021 < https://www.gasunie.nl/en/news/dutch-german-cooperation-secures-european-future-of-hydrogen>

The VTS safety and integrity assessment

The VTS is made up of 51 pipelines under 46 individual licenses; work will need to be completed to understand what impact the introduction of hydrogen might have on each one of these pipelines. Assessing an interconnected network like the VTS will be complex and time consuming and is anticipated to take at least five years. APA is the only entity with the knowledge and required skillset to assess the compatibility of the VTS pipeline and associated facilities.

There is currently no Australian standard for design of new hydrogen pipelines or conversion of existing infrastructure[19], but there is work in progress to incorporate hydrogen in future updates of AS2885. The Australian Pipelines and Gas Association (APGA) is also developing a Hydrogen Code of Practice which will provide guidance to industry in the absence of formal published standards.

This detailed technical assessment is required because, when designed and constructed, the existing pipelines design only considered natural gas compatibility, so our records only contain data and information that is relevant for natural gas service. For us to understand the impacts of hydrogen, and in particular the changes to ductility, toughness, and fatigue life, we need to collect additional information about our pipelines with hydrogen service in mind.

Pipelines constructed from low grade steel with thick walls are known to be less susceptible to hydrogen embrittlement, based on international literature and existing hydrogen pipeline standard ASME B31.12. A large proportion of Australia's transmission network, including some parts of the VTS, are manufactured with thinner wall, higher stress, and higher-grade pipeline materials, where the impact of hydrogen and hydrogen embrittlement must be managed.

This proposed safety and integrity assessment will provide sufficient data to quantify the impacts of hydrogen embrittlement on the VTS network, and any changes required to current operating parameters to mitigate identified safety and integrity risks.

4 Risk Assessment

If hydrogen enters the VTS network without completion of the proposed technical assessments, there will be an unknown impact on the integrity of the pipeline which may lead to premature degradation or failure of pipeline or facilities elements. This could ultimately lead to health and safety risks for members of the public, our customers, staff and contractors.

Table 2: Risk Rating

Risk Area	Risk Level
Health and Safety	High
Environment	Moderate
Operational	High
Customers	High
Reputation	High
Compliance	High
Financial	High
Final Untreated Risk Rating	**High**

Full risk assessment available upon request.

[19] Australia's natural gas pipeline standard AS2885 does not currently address hydrogen. ASME B31.12 is the US standard for hydrogen pipelines, but this standard is difficult and potentially impractical to apply retrospectively to transmission pipelines such as the VTS. Our Parmelia Gas Pipeline Conversion Project assesses the gaps between these two standards and uses a risk-based approach to assess and mitigate the threats and consequences introduced or altered due to the introduction of hydrogen to the pipeline to meet the safety management intent of Australian pipeline standard AS2885.

5 Options Considered

5.1 Option 1 – Do Nothing

The Do Nothing option is to not complete any hydrogen-compatibility technical assessment on the VTS. As a result, there are two scenarios that could result:

1. Hydrogen enters the VTS network without completion of the proposed technical assessments, and there is an unknown impact on the integrity of the pipeline. This is likely to result in unacceptable health and safety risks for members of the public, our customers, and our staff and contractors.

2. Hydrogen is not permitted to enter the VTS, which would likely require one or several of the following:

    a. Reconfiguration of the VTS. The VTS is a complex interconnected network, and there is a possibility that hydrogen injected either upstream or downstream by another gas infrastructure owner/operator could make its way into the VTS network. This would result in Scenario 1 above. To prevent this from happening APA would need to assess the network for interface risks and modify infrastructure to prevent inadvertent hydrogen flow (this is un-costed and has not been included in the Do Nothing option).

    b. Investment in new hydrogen-dedicated pipelines and assets to be built at a higher cost than repurposing existing infrastructure.

    c. Additional costs / technical hurdles that may hinder or prevent potential decarbonised / renewable gas projects from proceeding e.g. a renewable gas project not connected to the Melbourne distribution network would need to investigate alternative methods of transporting hydrogen. This would result in Scenario 2b above, or alterative hydrogen transportation methods.

Feedback from the VTS stakeholder roundtables is generally accepting of the need to complete an assessment of hydrogen-compatibility to support the transition of the gas network in a decarbonised future. It is understood that this support is underpinned by a desire to maintain system security and safety, and to optimise the cost of supply of energy across both the gas and electricity networks. There is recognition that significant work needs to be done to better understand the viability of repurposing the existing natural gas network for hydrogen service, and that there is a genuine urgency to commence the work to support decarbonisation efforts.

5.1.1 Cost/Benefit Analysis

The benefit of the Do Nothing option is the avoidance of capital expenditure.

The cost of the Do Nothing option is to accept the health and safety risks for members of the public, our customers, staff and contractors. If hydrogen was to enter the VTS network without APA completing sufficient safety and integrity studies, there is a risk of a full-bore pipeline rupture resulting from degradation of the integrity of the pipeline material due to unquantified hydrogen embrittlement impacts. Given that VTS pipelines traverse through Greater Melbourne, this has obvious consequences for public safety and a possible long-term interruption to the provision of pipelines services.

Until sufficient technical assessment has been undertaken, APA is unable to demonstrate that safety and integrity risks of operating the VTS with hydrogen blend have been mitigated as far as practicable.

The Do Nothing option also increases the risk of a lesser event caused by the same threat (e.g., a significant pipeline leak). The likelihood of this type of event is greater than the likelihood of a full-bore rupture.

In addition, the VTS will be unable to carry hydrogen until technical assessments can be completed to quantify the impacts of hydrogen embrittlement. This also means that if hydrogen is injected either upstream or downstream by another gas infrastructure owner/operator, the VTS will require reconfiguration which will have cost implications (currently undetermined).

If the safety risks of introducing hydrogen to the VTS are not quantified and mitigated, this limits the opportunities to repurpose existing infrastructure to transport large volumes of hydrogen from point of production to point of use to enable a low-carbon future. This may result in a requirement to build new dedicated hydrogen pipeline network, at a cost that is higher than repurposing existing natural gas infrastructure.[20]

5.2 Option 2 – Technical assessment of pipeline, including materials testing and facilities screening

The objective of this proposed option is to provide sufficient data to understand the impacts of hydrogen embrittlement on the VTS. The information will allow APA to quantify:

- the safety and integrity impacts and suitability for hydrogen blending,
- any remedial works or modifications required for facilities and assemblies, or
- changes in operation required to ensure continued safe operation of the VTS.

At the conclusion of the project, a final report will be produced for each of the pipelines that has been tested and assessed, providing a robust and engineering-based approach to determining the suitability of the VTS network for hydrogen blending. Each report will collate all relevant information into a single document, including the findings and recommendations about the line pipe, pipeline laterals, pipeline assemblies and facilities, as well as the outcomes from the Safety Management Study (SMS) review with Energy Safe Victoria (ESV).

These pipeline reports will be used to support APA's VTS strategic network planning allowing us to clearly identify which parts of the network are suitable for hydrogen blending, and which are not.

APA has sought feedback from customers through APA's VTS AA Roundtable sessions, as well as stand-alone hydrogen information sessions, and through circulation of the VTS AA First Look Document.

Feedback from stakeholders has been generally supportive of hydrogen as an alternative fuel to natural gas. It is understood that this support is underpinned by a desire to maintain system security, and to optimise cost of supply of energy across both the gas and electricity networks. There is recognition that significant work needs to be done to better understand the safety and integrity implications of repurposing the existing natural gas network for hydrogen blends, and that there is a genuine urgency to commence the work to support decarbonisation efforts.

The primary concern raised during the stakeholder consultation process was how the technical assessment would be funded and the impact to consumer tariffs. APA's tariff modelling estimates that the bill impact of this assessment is ~$2c/GJ which equates to approximately $1.10 per year for domestic customers, and approximately $10 per year for business customers.

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[20] Clean Energy Finance Corporation, Australian hydrogen market study, 24 May 2021, <https://www.cefc.com.au/media/nkmljvkc/australian-hydrogen-market-study.pdf>

5.2.1 Cost/Benefit Analysis

The benefit of Option 2 is that the assessment will provide sufficient data to quantify the impacts of hydrogen embrittlement on the VTS and demonstrate how renewable gas can be safely and reliably transported in the VTS, optimising energy supply to consumers. This assessment will be used to support APA's VTS strategic planning process, clearly identifying which parts of the network are suitable for hydrogen blending, and which are not.

For those parts of the network identified as suitable for hydrogen blending, the information gathered will inform what mitigations need to be implemented to maintain the safety and integrity of the network once hydrogen is introduced. This will result in a significantly reduced risk profile. Full risk assessment available upon request.

Through this technical assessment, if we can safely accommodate hydrogen in the VTS network, there is the added benefit of supporting decarbonisation goals of the Victorian Government and as a result we may also be able to extend asset lives, thus reducing depreciation charges to customers (noting that this has not been quantified).

5.2.1.1 Cost Estimation Methodology

The VTS comprises of approximately 2,262 km of high-pressure gas transmission pipelines made up of 51 pipelines under 46 individual licenses. In preparation for the VTS access arrangement submission, APA has completed preliminary desktop analysis of the network, including a high-level screening assessment for each of the pipelines and associated assemblies / facilities to determine the costs to complete the proposed safety and integrity assessment. The cost estimation methodology is summarised in Figure 3 below. Our approach is underpinned by our understanding of the potential effects of hydrogen embrittlement, balanced by a pragmatic test approach that will optimise cost impacts to customers whilst maintaining the safe operation of the network.

The desktop analysis and high-level screening assessment for this VTS safety and integrity assessment has been developed in line with industry best practice and greatly informed by our learnings from our Parmelia Gas Pipeline (PGP) Conversion Project.

Through our PGP Conversion Project we have established an international advisory panel of experts[21] who have guided the development of our test program and provide ongoing input and guidance to validate our approach and test results. This PGP project and associated test program has created inhouse knowledge and has formed the foundation of the proposed VTS safety and integrity assessment.

[21] The international advisory panel includes European representatives who were directly involved in the conversion of a Gasunie pipeline from natural gas to hydrogen; an independent fracture mechanics expert who authored the pipeline defect assessment manual; and the leader of Sandia's Hydrogen Materials Lab and Hydrogen Compatibility Consortium in the USA.

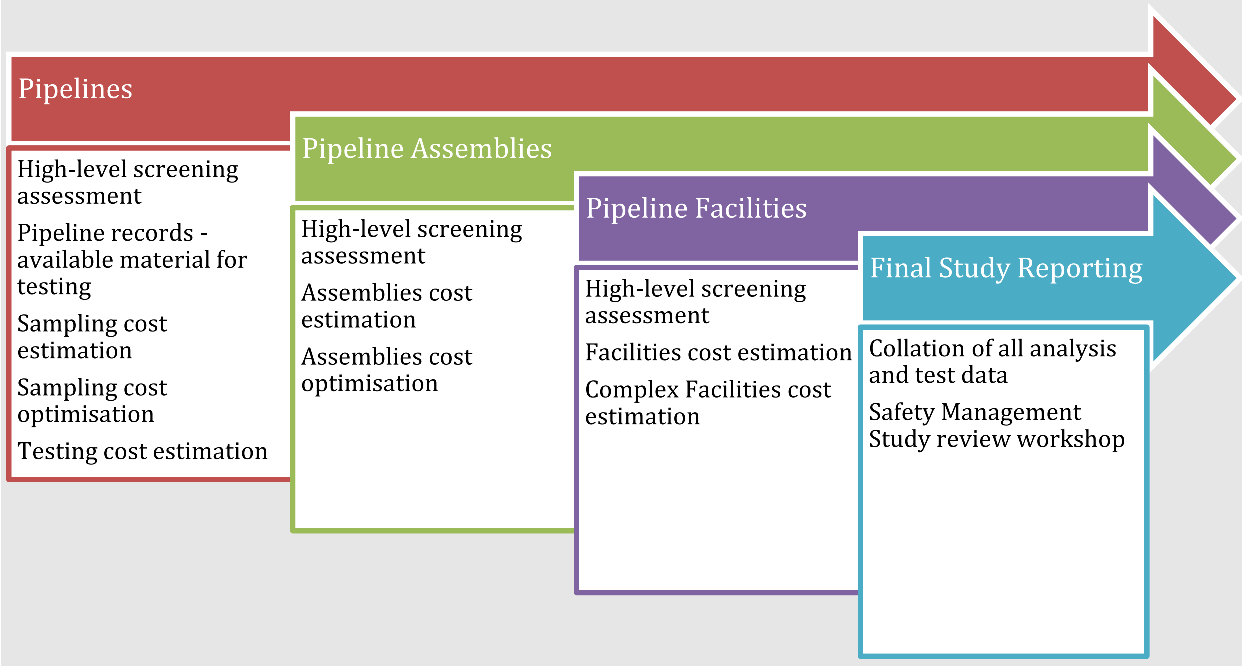

Figure 3: Overview of Cost Estimation Methodology

5.2.2 Pipelines

A high-level screening assessment was conducted to understand the operating pressure, grade, and design factor of each pipeline[22]. A sensitivity analysis was also undertaken based on known material integrity issues, diameter and design stress taking into consideration fracture behavior of low stress and small diameter pipelines.

Recognising the scale of the assessment required, through this initial screening, APA has allocated all of the VTS pipelines to one of two phases: Phase 1 (this assessment) and Phase 2 (future assessment if required). Phase 2 pipelines are those pipelines which are interstate import/export lines and are expected to remain as natural gas only pipelines for the period of this Access Arrangement. This results in a high-pressure natural gas "ring" around the state from Longford to Dandenong to Wollert (with the VNIE NSW interconnector), and then from Wollert to Brooklyn and onto Iona underground gas storage facility. Phase 2 pipelines can be assessed in future, if determined to be required for hydrogen blending.

Phase 1 includes the balance of the network. Of the 51 pipelines, 39 pipelines have been identified as requiring detailed assessment in Phase 1[23].

Following the high-level screening assessment, pipeline records were assessed for available material test certificates, hot-tap coupons / cut-out samples, and ER/Stock pipe to determine material available for testing and if additional samples were required to be obtained from in-service pipelines.

Where additional samples were determined to be required the type and number of samples were estimated based on the screening assessment.

[22] Several licenses / pipelines have more than one section or pipeline steel manufacturer and will therefore require testing and assessment per section due to differing operating pressures / conditions or loops.

[23] APA notes that this preliminary screening of pipelines may be amended based on optimisation of the network driven by system modelling and potential injection points driven by market demand.

Line pipe sampling involves excavating the in-service pipeline, completing non-destructive testing (NDT) to confirm condition of line pipe at the point of extraction, welding of hot tap fittings, and extraction of a sample from the live pipeline.

Based on the initial high-level screening assessment, sampling costs were found to be very high. To optimise costs and reduce sampling, a follow-up assessment was made to group where pipeline materials of the same age, steel grades and physical properties (WT and diameter) that might be tested together.

A second assessment was also made where pipelines consisted of short interconnects, offtake connections, or lengths (<2km) with low grade and design factor and testing revised to an 'in situ' assessment the scope of which would include hardness, metallography, and chemical analysis to reduce the sampling costs.

The 'in situ' assessment involves excavating the in-service pipeline, removing a small amount of surface material to complete in situ chemical analysis, hardness, and metallography to examine the microstructure for the base metal and girth weld (we may also be able to identify the seam weld). This will give us indication of the grade, hardness / tensile strength and the microstructure which should allow us to make an assessment on the risk and suitability for these short sections; or in a worst-case scenario identify the need for further work / assessment. Most are understood to be low grade, thick wall, which we can then apply the existing international hydrogen pipeline standard (ASME B31.12) approach, by looking at low stress and low-grade parameters.

Table 3: Summary of Cost per Sample[24]

Sample Type	Description	Cost per Sample
HTC <DN350	Hot Tap Coupon of 14-inch diameter pipe	$160,000
HTC DN400 – DN750	Hot Tap Coupon of 16-inch – 30-inch diameter pipe	$240,000
HTS <DN350	Hot Tap Stopple of 14-inch diameter pipe	$650,000
HTS DN400 – DN750	Hot Tap Stopple of 16-inch – 30-inch diameter pipe	$1,000,000

Following collection of the samples, the pipeline material will undergo materials testing to compare the baseline material properties (air test) against the material properties after exposure to hydrogen (H2 test). The pipeline material properties in hydrogen will then be used to assess the impacts of hydrogen on pipeline design and operation including fracture control, mechanical damage resistance, and fatigue performance. The pipeline condition will be assessed against revised defect assessment criteria accounting for the potentially degraded material properties. Where property degradation is determined to impact operation, a revised operating envelope will be defined for assessment by capacity planning.

Table 4: Testing Cost per Sample[25]

Test Type	Test Cost / Sample
Air Test	$5,000
H2 Test	$50,000

[24] A hot tap coupon (HTC) is a localised extraction of a material coupon from the pipeline. A hot tap stopple (HTS) is more invasive and requires a full bypass of the live pipeline while a sample is extracted. The pricing estimates are based on recent pricing for the two diameter ranges.

[25] Testing costs are based on recent Parmelia Gas Pipeline (PGP) pricing, assuming testing can be completed at University of Wollongong, rather than using commercial overseas laboratories where testing costs have been quoted in excess of 3x PGP pricing.

5.2.3 Pipeline Assemblies

Pipeline Assemblies include main line valves (MLV) and scraper stations. The preliminary desktop analysis of the network identified 128 MLV and 39 Scraper Stations to be assessed. Typically, MLV's are welded in line and each MLV assembly will be generally consistent along the pipeline (particularly in regional areas). It is proposed that for each pipeline a typical MLV and all Scraper Stations will be assessed by site visit and desktop assessment of the balance of MLV's. Assessment will consider changes in stress and design factor requirements for assemblies in hydrogen service with consideration of international design standards. Suitability of existing inline equipment such as instrumentation and control / actuated valves, and impacts of hydrogen on materials flow behavior, hazardous areas and functional safety will be screened.

5.2.4 Pipeline Facilities

Pipeline facilities, including metering and offtake stations, will require assessment similar to the above for pipeline assemblies, but with potential for more complex equipment including type B equipment such as water bath heaters. The preliminary desktop analysis of the network identified approximately 151 meter / offtake stations to be assessed. The assessment process will be similar to the pipeline assembly assessment, requiring a site visit, equipment and technical assessments and development of screening and modification requirement report for the facility.

There are also three complex facilities that require assessment:

- Dandenong City Gate
- Wollert Compressor Station and City Gate
- Brooklyn Compressor Station and City Gate

These will require similar types of assessment works to the above however, these much larger and complex facilities will also include additional piping system separation concept works required for hydrogen and non-hydrogen system planning, and additional equipment assessment including complex equipment assessment (such as compressors). In the cases of compressor stations and Type B appliances, original equipment suppliers will be engaged to assist assess suitability and hydrogen limits of their equipment.

5.2.5 Safety Management Study and Final Assessment Reporting

Once the assessment data is available, each pipeline will undergo a Safety Management Study (SMS) review workshop involving the project team, pipeline engineering, operations engineering, asset management, field services and Energy Safe Victoria (ESV).

It is proposed that for each pipeline a final report will be produced, collating the line pipe, pipeline lateral, pipeline assemblies, pipeline facilities, and SMS findings / recommendations into a single document.

5.3 Summary of Cost Benefit Analysis

Table 5: Summary of Cost/Benefit Analysis

Option	Benefits (Risk Reduction)	Costs
Option 1	Do Nothing	$0k
Option 2	Technical assessment of pipeline, including materials testing and facilities screening	$37,861,536

5.4 Proposed Solution

5.4.1 Proposed Solution – Technical assessment of pipeline, including materials testing and facilities screening

APA, through a high-level screening assessment has identified 39 pipelines within the VTS that require sampling, materials testing, and detailed assessment to quantify the impacts of hydrogen embrittlement. The proposed technical assessment includes the pipeline as well as the associated pipeline assemblies and facilities connected to these 39 pipelines.

At the conclusion of the project, the information will allow APA to quantify the integrity impacts and suitability for hydrogen blending, and any remedial works or changes in operation required to ensure continued safe operation of the VTS with the introduction of hydrogen.

These final reports will be used to support APA's VTS strategic network planning allowing us to clearly identify which parts of the network are suitable for hydrogen blending, and if any are not. These inputs will also support the Victorian Government's long-term planning for a low-carbon future with clean molecules; as well as the AEMO systems planning process to ensure the ongoing security of supply of energy.

5.4.2 Why are we proposing this solution?

As described above, it is critical that APA as the VTS pipeline owner and operator undertakes technical assessments that enable quantification of the impacts of hydrogen embrittlement before *any* quantity of hydrogen gas enters the VTS network.

In the context of the changing regulatory landscape, and the expedited amendments to the National Gas Law to incorporate hydrogen blends, biomethane, and other renewable methane gas blends, the urgency of completing this assessment has increased significantly.

There is a clear responsibility for implementing this solution. The Gas Safety Act and the Pipelines Act require APA as owner of these pipelines to minimise risks as far as practicable. The Acts and Regulations also demand adherence to AS2885 which demands a similar risk tolerance.

Until sufficient technical assessment has been undertaken, APA is unable to demonstrate that safety and integrity risks of operating the VTS with hydrogen blend have been mitigated as far as practicable.

5.4.3 Consistency with the National Gas Rules

Consistent with the requirements of Rule 79 of the National Gas Rules, APA considers that the capital expenditure is such as would be incurred by a prudent service provider acting efficiently, in accordance with accepted good industry practice, to achieve the lowest sustainable cost of providing services:

- Prudent – The expenditure is necessary to maintain public safety and the safety of APA VTS personnel and to maintain the integrity of pipelines in light of government policy decisions to include hydrogen in the national gas market framework. The technical assessment will provide information to assess the viability of transporting hydrogen on VTS pipelines and aligns with ALARP principles and is of a nature that a prudent service provider would incur.
- Efficient – The technical assessment is bespoke for the VTS and we have drawn on APA's work on the Parmelia gas pipeline conversion, and international expertise. APA has selected the least number of pipelines to study (39 out of 51) to ensure scope and cost is minimised. The field work will be carried out by APA approved contractors, who have demonstrated specific expertise in completing hot tap welding in a safe and cost-effective manner. The expenditure can therefore be considered consistent with the expenditure that a prudent service provider acting efficiently would incur.
- Consistent with accepted and good industry practice – The current evolution of our industry and the focus on alternative energy sources means we must address the risks associated with introducing hydrogen to a high-pressure natural gas system. We are required to ensure risk is as

low as reasonably practicable in a manner that balances cost and risk, consistent with Australian Standard AS2885. The proposed technical assessment is consistent with good industry practice.

- To achieve the lowest sustainable cost of delivering pipeline services – The sustainable delivery of services includes reducing risks to as low as reasonably practicable and maintaining reliability of supply.

5.4.4 Forecast Cost Breakdown

The costs summarised in Table 6 below have been derived through the high-level screening assessment, as described in section 5.2.

Table 6: Summary of costs for technical assessment of pipeline, including materials testing and facilities screening

Activity	Estimated Cost	Cost Estimation Methodology
Line Pipe Sampling (collection / extraction of samples)	$ 12,780,000	Section 5.2.2
Line Pipe Testing (laboratory testing of samples)	$ 4,266,000	
Lateral in Situ Inspections	$ 5,808,000	
Pipeline testing data collation, assessment, and reporting (one report per pipeline tested)[26]	$ 2,021,760	
Pipeline Assemblies Assessment	$ 2,620,800	Section 5.2.3
Facilities Assessment	$ 7,299,072	Section 5.2.4
Complex Facilities Assessment	$ 900,000	
Safety Management Workshops and Studies[27]	$ 1,491,984	Section 5.2.5
Final Reporting (one report per pipeline tested, incorporating analysis and conclusions for line pipe, associated laterals, pipeline assemblies, facilities, and safety management study recommendations)[28]	$ 673,920	
Total	**$ 37,861,536**	

5.4.5 Exclusions and Assumptions

The focus of this assessment will be on the VTS only. The assessment will seek to understand the integrity impacts and suitability for hydrogen blending, and any remedial works or changes in operation required to ensure continued safe operation of the VTS with the introduction of hydrogen.

[26] An allowance of 4 weeks for screening assessment and data collection plus 2 weeks for a senior engineer to prepare the report has been included for each of the 39 pipelines tested

[27] An allowance of 4 days for each of the 39 pipelines has been included – the Safety Management Study assessment team will include representatives from: the project team, pipeline engineering, operations engineering, asset management, field services, Energy Safe Victoria, plus an external facilitator

[28] Collation of all pipeline test information and associated assemblies / facilities – an allowance of 2 weeks for a senior engineer to prepare the report has been included for each of the 39 pipelines tested

- No remedial works to make pipelines ready for hydrogen operation is included in the estimate.
- Activities such as making consequential updates to existing documents or updating documents for AS2885 compliance for hydrogen blending (including preparing revised fracture control plans, isolation plans, and vent blow down studies based on engineering assessment findings) are not included in the estimate.
- No physical works for hydrogen readiness including re-hydrotest, replacement / upgrade of equipment at facilities is included in the estimate.

5.5 Stakeholder Engagement

APA has undertaken extensive stakeholder engagement in preparation of the overall VTS access arrangement. In total, APA hosted 12 stakeholder roundtable sessions and two information sessions which were designed as open feedback forums where interested parties could ask questions, seek clarifications, and constructively challenge assumptions underpinning the access arrangement submission.

Over the course of the stakeholder engagement journey, we have been discussing the potential to repurpose the VTS to transport hydrogen. At the Capital Issues Workshop in July (prior to the Energy Ministers' announcement), we suggested undertaking an assessment of VTS pipelines to ascertain their ability to accommodate hydrogen in the gas stream. At this suggestion, stakeholders raised several points including:

- Some stakeholders considered there was merit in an assessment being undertaken
- There were concerns about the cost and who should fund such an assessment; some stakeholders did not support customers funding the assessment
- There was a request for APA to work with gas storage facility owners on the implications for them
- More generally there was a question about whether hydrogen 'was the answer' and concerns about costs to customers for changing to hydrogen compatible appliances
- There was a general concern at the lack of a policy on energy and climate change overall to drive these types of policy decisions.

In response to the above queries, APA hosted a one-hour hydrogen workshop on 26 August 2021 to provide stakeholders with further details on the challenges and opportunities posed by introducing hydrogen into the VTS network. During this workshop, stakeholders posed a range of questions and raised several points including:

- A broad desire and need for public education campaigns about hydrogen and safety
- Acknowledgement that the transition from town gas (which was a mixture of hydrogen and carbon monoxide) to existing natural gas specifications required users to update their appliance burner configurations; and that this transition from natural gas to potential hydrogen blends will require similar appliance upgrades
- Suggestion for APA to align the scope of the technical assessment with distribution networks who are investigating the introduction of 10% blend of hydrogen
- Concern about the economics of hydrogen and the likelihood of achieving the Government's target of $2/kg
- Emphasis that there needs to be optimisation of costs between gas and electricity, noting that hydrogen causes sector coupling of both
- A question as to whether APA would consider producing hydrogen in future
- General interest in other hydrogen projects and programs that APA is pursuing.

Further to the roundtable stakeholder engagement sessions, APA circulated a First Look document on 15 October 2021 which included a high-level overview of the proposed hydrogen test program, the estimated costs, and subsequent tariff impacts. The costs shared with customers in the First Look document are the same as those included in this formal business case submission.

APA received two written submissions providing feedback on the hydrogen assessment in response to the First Look document. Feedback from one organisation requested further details about the test program and called for information to be provided to consumers about required appliance upgrades[29] as well as reiterating concerns about funding the test program by customers.

A second written response was received from AEMO who is responsible for operating the VTS network. AEMO's response acknowledged the benefits of the proposed assessment and its contribution to providing information about the possible future of pipelines as Australia decarbonises. AEMO also identified the need to assess the network as a whole: "as the pipelines in the VTS are interconnected, if hydrogen is blended into one pipeline, it will most likely disperse into the other pipelines. Therefore, the approach should be to assess all the VTS pipelines[30]".

At the final VTS roundtable discussion, APA discussed the importance of the test program to understand and mitigate the safety and integrity implications of the Government's policy to expedite bringing hydrogen into the national gas market framework. APA also presented further information on the tariff and bill impacts of the safety assessment. At this session there was broad acceptance for the need to complete an assessment of hydrogen-compatibility to support the transition of the gas network in a decarbonised future, but continued uncertainty as to the best source of funding. APA's tariff modelling estimates that the bill impact of this assessment is ~$2c/GJ which equates to approximately $1.10 per year for domestic customers, and approximately $10 per year for business customers.

In addition to the VTS roundtable discussions, APA has received numerous unsolicited approaches by several developers seeking to produce hydrogen in Victoria. These developers view blending hydrogen into the gas network as a critical base offtake that will support the future of a hydrogen emerging industry. Some developers have relatively small offtake expectations, whereas others have significant volumes of hydrogen that they are seeking to blend into the gas network. Fundamentally, these projects are not located near the main distribution network for Melbourne and will require transportation via the VTS (or another transportation method e.g. a dedicated hydrogen pipeline or tube trailer). This demonstrates the growing need to assess the viability of the VTS to transport hydrogen blends, and the urgency to commence the process.

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[29] APA notes that customer appliance testing is outside of the scope of this technical assessment. This assessment is focused only on the safety and integrity of the transmission pipeline network in response to the expedited amendments to the National Gas Law

[30] APA has optimised the costs in this access arrangement proposal by proposing a staged assessment methodology, as described in section 5.2.2

Appendix A – Risk Assessment

Available upon request.

Appendix B – Parmelia Gas Pipeline Conversion Project – Phase 1 Findings

Refer to VTS - VTS Business Case 200. Hydrogen safety and integrity. Appendix B - Australia's First Hydrogen Pipeline Conversion Project - December 2021 - Public.