Challenging today.
Reinventing tomorrow.

# Towards a zero carbon future

The role of wastewater treatment plants in accelerating the development of Australia's hydrogen industry

# A MESSAGE FROM OUR EXECUTIVES

*Jacobs is a long-standing partner to Yarra Valley Water in delivering essential water and sanitation services to more than two million people in Melbourne's growing northern and eastern suburbs. We're proud to build on this relationship by producing this thought leadership paper. Together, we aim to start a conversation about the potential role of water utilities in accelerating the development of Australia's hydrogen industry.*

In a world undergoing rapid transformation, we need problem-solvers and innovative solutions to challenge the way we work today and reinvent tomorrow. As we operate against a backdrop of a growing population, changing climatic conditions and increased demand for our services, this is especially relevant to how we tackle global decarbonisation. Although we're seeing rapid growth in renewable energy investment, the pathway to a zero carbon future in many energy-intensive sectors remains a challenge. Decarbonising these areas is one of the most critical issues faced by our generation, as emphasised by António Guterres, Secretary-General of the United Nations, in an address to world leaders:

> **"Climate change is the defining issue of our time – and we are at a defining moment."**

'Sustainable hydrogen' – produced using recycled water and renewable energy sources - is one of the many avenues that may support us on our journey to decarbonisation. In Australia, however, cost is currently a barrier to widespread adoption. In this paper, we explore the uniquely synergistic relationship between the water sector and hydrogen production that is both positive for the environment and supports the commercial readiness of this emerging industry.

This paper is a snapshot of the shared passion of our people and we hope it inspires readers across industries to push the limits of what's possible and create solutions for a more connected, sustainable world.

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# FOREWORD

In May 2019, Jacobs released a thought leadership paper titled *Australia's pursuit of a large scale hydrogen economy: Evaluating the economic viability of a sustainable hydrogen supply chain model.* The paper asked whether hydrogen could live up to its potential for economic growth without compromising Australia's broader sustainability goals, including emissions reduction and water security. The question was raised in response to industry conversations at the time which had largely neglected one critical issue: under the current electrolysis-based supply chain model, hydrogen production in Australia may not be sustainable in the context of our drought-prone climate and fossil fuel dominated energy landscape.

The 2019 paper set out to measure the commercial viability of a new sustainable supply chain model which uses recycled water and renewable energy. Although the potential of a sustainable model was recognised, the analysis highlighted that improving its viability at scale would require further consideration. However, the paper did uncover a cost-effective and environmentally friendly role for recycled water in hydrogen production, and the source of water now forms an important part of project decisions.

Creating cost-effective sustainable hydrogen remains a challenge today, with the Australian Government directing funding towards measures that can reduce prices and stimulate its adoption. This brings us to our current thought leadership paper, which has been developed in partnership with Yarra Valley Water. Building on the role for recycled water in hydrogen production, we take our thinking a step further and question whether water utilities have a more pivotal role to play.

Electrolysis produces two products — hydrogen and pure oxygen. Pure oxygen is a valuable resource to wastewater treatment plants, increasing the efficiency of the energy-intensive aerobic treatment processes most commonly adopted by the industry. The potential to use oxygen in the treatment process could give value to what has traditionally been described as a 'by-product' of electrolysis, representing an opportunity to partially subsidise hydrogen production and increase its commercial viability.

In this paper, our high-level analysis explores the symbiotic relationship between oxygen demand and hydrogen price to better understand the opportunity in co-located wastewater treatment plants and hydrogen facilities. In doing so, we hope to stimulate discussion and carve out a potential path forward to accelerate the commercialisation of Australia's hydrogen industry.

# AUTHORS & CONTRIBUTORS

As our world undergoes rapid transformation and the challenges we face become increasingly complex, we must look across sectors and encourage meaningful collaboration. It is only in doing so that we can develop innovative solutions that will drive sustainable growth into the future.

In partnership with Yarra Valley Water, this paper has been authored by Jacobs' global network of professionals, who take a cross-sector approach to address some of the world's most critical challenges and advance conversations that matter.

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# EXECUTIVE SUMMARY

## The challenge

As a flexible energy carrier and enabler for the international trade of renewable energy, hydrogen could play an important role in our drive towards a sustainable, decarbonised future.

In Australia, industry analysis indicates that demand for hydrogen will be generated if priced between $2-6/kg. The Australian Government has identified that hydrogen would need to be priced at approximately $2/kg, as reflected through their 'H2 under 2' goal, for it to compete with alternative energy sources. For broader applications such as mobility, analysis indicates a range of $4-6/kg would allow it to compete with alternatives.

Reducing the cost of hydrogen to reach this price range remains a major barrier to widespread adoption, with the industry currently facing a 'chicken or egg' dilemma: to reduce hydrogen costs compared to alternatives, the overall market must reach the level of demand necessary to achieve economies of scale, but lower costs are needed to facilitate growth in demand. Opportunities to improve financial viability of early entrants are therefore key to accelerating the development of Australia's hydrogen industry.

Overcoming the cost challenge is a key focus of the Council of Australian Governments (COAG) Energy Council's *Australia's National Hydrogen Strategy*. The Strategy outlines how creating 'hydrogen hubs' — clusters of demand in regions where buyers are co-located — could provide the industry with a 'springboard to scale' by making hydrogen infrastructure development more cost-effective.

## The opportunity

Hydrogen hubs are more likely to be effective in locations where existing infrastructure can be leveraged and renewable energy and water are readily available. Which leads us to the wastewater treatment industry. Not only do many wastewater treatment plants (WWTPs) have favourable site conditions for hydrogen production, they may also be uniquely placed to improve the commercial viability of early entrants into the market.

With over $300 million of Federal funding available, in addition to multiple state-based funding schemes in place, now is the time to explore the potential role of WWTPs in Australia's emerging hydrogen industry.

> **So, in this paper, we asked ourselves 'what if' the growth of Australia's domestic hydrogen market could be supported by co-locating hydrogen production at wastewater treatment plants?**

To date, discussions regarding the role of the water sector in hydrogen production have focused on the importance of water as a resource for electrolysis. But water utilities may have a more pivotal role to play. Electrolysis produces two products – hydrogen and pure oxygen. Pure oxygen is a potentially valuable resource to WWTPs as it can increase the efficiency of energy-intensive aerobic treatment processes that are most commonly used to treat wastewater.

With many of Australia's WWTPs looking to upgrade or increase their capacity, a transition towards oxygen-based treatment could give value to what has traditionally been described as a 'by-product' of electrolysis. This represents a unique opportunity to partially subsidise hydrogen production with the sale of oxygen and increase its commercial viability.

## What we assessed

Our high-level assessment explored the potential benefits of transitioning to oxygen-based wastewater treatment and the impact that this would have on the commercial viability of co-located hydrogen production. To improve the relevance of our results, Yarra Valley Water's Aurora wastewater treatment plant was used as a case study.

## Overview of findings

The findings from our case study indicated that implementing a type of oxygen-based treatment (Membrane Aerated Biofilm Reactor (MABR)) at the Aurora WWTP could deliver net capital and operating cost savings to Yarra Valley Water compared to other types of treatment options tested.

> **At the same time, the guaranteed demand for oxygen at the Aurora WWTP was instrumental in enabling the co-located hydrogen facility to be commercially viable while selling hydrogen within a competitive price range of $2-6/kg.**

## Implications for Australia's hydrogen strategy

A guaranteed demand for the oxygen from wastewater treatment is a promising avenue for increasing the commercial viability of co-located hydrogen production.

- Co-located hydrogen production at WWTP sites could act as a catalyst for hydrogen hub development by improving the financial viability for early entrants.
- A best-practice process repeated regionally would allow hydrogen demand and infrastructure to scale beyond local applications and support inter-state and international supply chains.
- Co-located hydrogen production at WWTPs could support the Australian Government's 'H2 under 2' economic target.
- The competitive price range in our case study was achieved for 'sustainable hydrogen' – produced using recycled water and renewable energy. This could support faster decarbonisation of Australia's most emissions-intensive industries without compromising the nation's drinking water resources.

## Implications for the water sector

- The opportunity to use oxygen in certain wastewater treatment technologies to generate net savings suggests that it should be considered in future WWTP designs, especially if the oxygen can be cost-effectively sourced from a co-located hydrogen facility.
- The oxygen supply produced from hydrogen production could be scaled for other beneficial applications which could deliver additional cost savings for water utilities.
- Selling hydrogen and oxygen would generate new revenue streams for the unregulated subsidiaries of water utilities.
- Additional demand for renewable energy from co-located hydrogen production could increase revenue for existing or future on-site generation (e.g. waste-to-energy or solar).
- Co-located hydrogen facilities and oxygen-based treatments could support water utilities in their emissions reduction targets. In addition, the adoption of treatment technologies such as MABR could reduce direct emissions such as nitrous oxide.
- Reducing the price of hydrogen and encouraging adoption by nearby users would directly contribute to improved air quality and reduce noise pollution for local communities.

# Key message

Our paper highlights how water utilities could have a pivotal role to play in accelerating the development of Australia's hydrogen industry. Co-locating sustainable hydrogen production with some types of oxygen-based treatments at WWTPs could bring wider economic and social benefits and could improve the prospects of developing hydrogen hubs. This could be an important step to creating a mature hydrogen industry and enabling more rapid decarbonisation of the nation's most emissions-intensive industries.

Whilst the results from our analysis are specific to the unique circumstances of the Aurora WWTP and we highlight potential caveats, the conservative nature of some of the core assumptions and sensitivity ranges tested suggest that they are promising.

Whenever a WWTP is due for a substantially-sized upgrade, we recommend that the benefits of transitioning to oxygen-based treatments be considered alongside an assessment of whether an on-site hydrogen facility would be commercially viable. In terms of future funding, grant providers might explore whether redirecting funding towards a faster transition to oxygen-based treatment as part of an overall hydrogen strategy could be more cost-effective.

A critical next step in realising the full potential of WWTP-based hydrogen hubs is to conduct detailed studies on the technical and commercial viability of co-locating hydrogen facilities at a range of WWTPs across Australia.

CHAPTER ONE

# Introduction

# **Australia's hydrogen industry:** Overcoming the 'chicken or egg' dilemma

As a flexible energy carrier and enabler for the international trade of renewable energy, hydrogen could play an important role in our drive towards a sustainable, decarbonised future.

The Australian Government has identified hydrogen as a new export product with potential markets in Japan, the Republic of Korea and Singapore.[1] A strong domestic market will be required to support Australia's export capabilities but is currently in early stages of development. Hydrogen, along with many other emerging technologies, still needs to bridge the gap between demonstration and widespread commercialisation. To achieve this, a variety of factors should be considered, including developing standards, reducing technical uncertainties, building strong supply chains and production capabilities, and developing end-use markets.

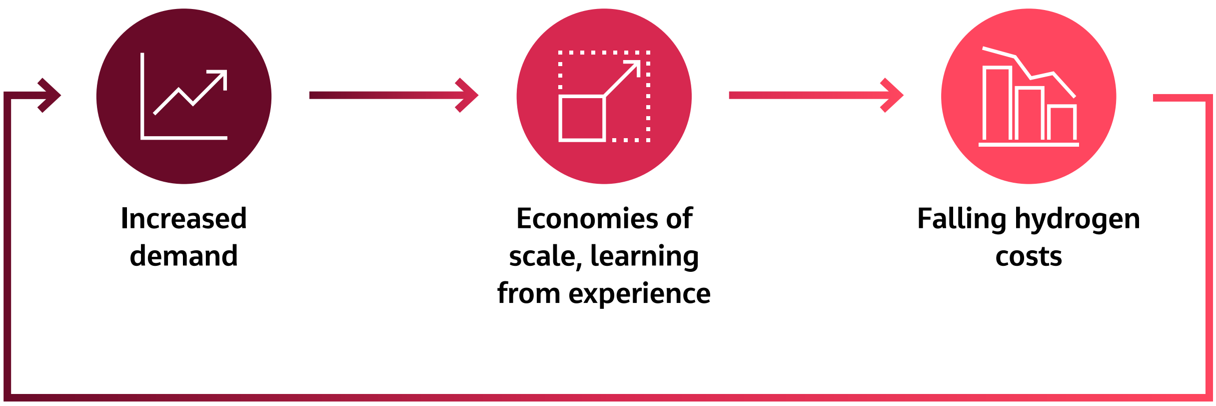
Underpinning these efforts is the need to improve the commercial viability of hydrogen production to attract investment and potential buyers. Recently, the Australian Government identified that hydrogen would need to be priced at approximately $2/kg, as reflected through their 'H2 under 2' goal, for it to compete with alternative energy sources.[2] For broader applications such as mobility, analysis indicates a range of $4/kg to $6/kg would allow it to compete with alternatives in the domestic market.[3,4]

Reducing the cost of hydrogen to reach this price range remains a major barrier to widespread adoption, and the industry faces a 'chicken or egg' dilemma: to reduce hydrogen costs compared to alternatives, the overall market must reach the level of demand necessary to achieve economies of scale but lower costs are needed to facilitate growth in demand. This mutually reinforcing relationship is reflected in **Figure 1.**

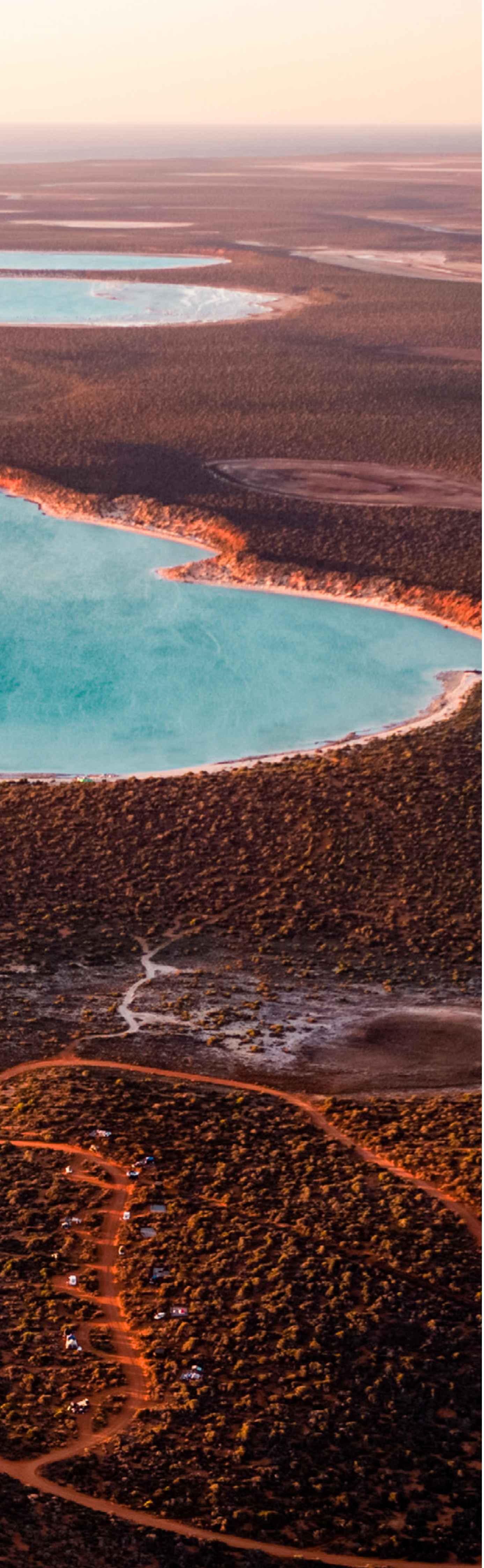


**FIGURE 1**

*Cycle of technology learning*




**Source:** Adapted from Figure 2.4 from 'Australia's National Hydrogen Strategy', COAG Energy Council (2019).





Overcoming this challenge is a key focus of the Council of Australian Governments (COAG) Energy Council's *Australia's National Hydrogen Strategy* ('the Strategy').[5] The Strategy outlines how creating 'hydrogen hubs' — clusters of demand in regions where buyers are co-located — could provide the industry with a 'springboard to scale' by making hydrogen infrastructure development more cost-effective, promoting efficiencies from economies of scale, and leveraging synergies from sector coupling.

The Strategy also outlines some of the conditions that could reduce the cost of hydrogen production and increase demand. Hydrogen hubs are more likely to be effective in locations where existing infrastructure can be leveraged and renewable energy and water are readily available. Which leads us to the wastewater treatment industry. Not only do many wastewater treatment plants (WWTPs) have favourable site conditions for hydrogen production, they may also be uniquely placed to further increase its commercial viability.

With over $300 million of Federal funding recently made available in addition to multiple state-based funding schemes in place, now is the time to explore the role of WWTPs in Australia's emerging hydrogen industry.

**In this paper, we ask 'what if' the growth of Australia's domestic hydrogen market could be supported by co-locating hydrogen production at wastewater treatment plants?**

# Co-located hydrogen production at wastewater treatment plants: A unique opportunity?

## Securing demand for oxygen could increase the commercial viability of hydrogen production

To date, discussions regarding the role of the water sector in hydrogen production have focused on the importance of water as a resource for the electrolysis process. Although the sustainability implications of sourcing water for hydrogen production should continue to be an important consideration in project development decisions, water utilities may have a more pivotal role to play. Electrolysis produces two products — hydrogen and pure oxygen. Pure oxygen is a potentially valuable resource to WWTPs as it can increase the efficiency of energy-intensive aerobic treatment processes that are most commonly used to treat wastewater.

Aging infrastructure, emissions reduction targets and the need to cater for growing populations means many of Australia's WWTPs are looking to upgrade or increase their capacity. This provides an opportunity for WWTPs to consider not only the efficiency improvements they could achieve by transitioning to pure oxygen-based treatments, but also how such a transition might support the commercial viability of hydrogen production.

If oxygen-based treatments can improve the efficiency of wastewater treatment and deliver significant net savings for water utilities, this could create a secure and growing local demand for oxygen.

This additional revenue stream could improve the commercial viability of hydrogen production and encourage market entrants by minimising the associated financial risks. If the commercial benefits are substantial enough to reduce the market price of hydrogen to within an acceptable range, co-locating production at WWTPs could stimulate demand from would-be buyers.

## So, why have we not used oxygen in wastewater treatment processes in Australia before now?

The removal of nutrients and pollutants in aerobic wastewater treatment is carried out by micro-organisms which need oxygen to break down the pollutants in the water. Conventional aeration technologies are not the most efficient way to deliver oxygen to these micro-organisms. But due to an abundance of low-cost fossil fuels and resulting low electricity costs, the effort of inefficiently transferring oxygen from air through the treatment system has been relatively inexpensive. Therefore, these processes were widely adopted by WWTPs across Australia.

Today, with the costs of energy, land and construction on the rise, those inefficiencies are becoming increasingly problematic. In addition, there have been advances in more efficient treatment processes in recent years, increasing their viability and cost-effectiveness. For example, treatment technologies such as Membrane Aerated Biofilm Reactor (MABR) have improved the delivery of oxygen compared to conventional aeration technologies (**Figure 2**).

Regardless of the technology used, switching from air (made up of about 20% oxygen) to pure oxygen in the treatment process could increase treatment capability and reduce associated operational and capital costs.

**FIGURE 2**

*Conventional aeration vs MABR treatment technologies*

Conventional aeration treatment technologies deliver oxygen to the micro-organisms used in the treatment process by pumping air through diffusers to create bubbles. This is energy-intensive because air only has a small proportion of oxygen, so much larger volumes need to be supplied. In addition, the bubbles rise too quickly for the micro-organisms to absorb the optimal amount of oxygen they need to thrive. As a result, the efficiency of this treatment process is limited.

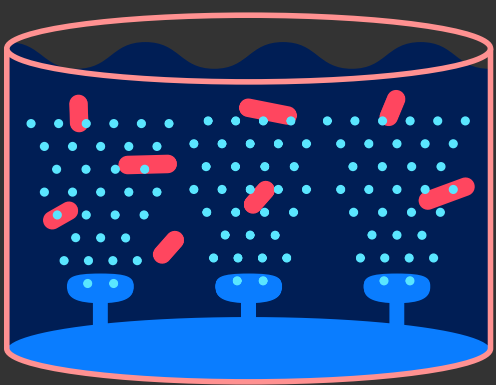
In comparison, treatment technologies such as Membrane Aerated Biofilm Reactor (MABR) deliver oxygen to the micro-organisms very differently. Rather than the micro-organisms absorbing oxygen from air bubbles in the water, air is fed at low pressures through the membranes, delivering oxygen directly.

The result is a far more effective transfer of oxygen to the micro-organisms, improving the efficiency of the treatment process. Switching from air to pure oxygen in the treatment process results in even greater efficiencies.

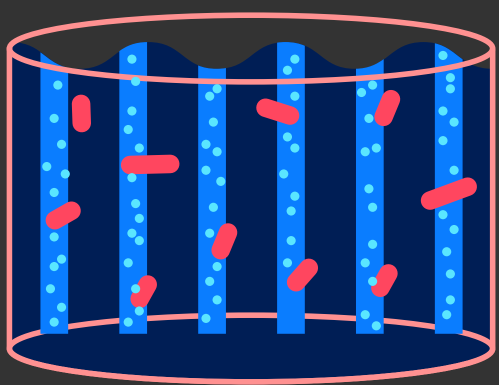
These increased efficiencies mean oxygen-based MABR technology has the potential to greatly reduce the energy and capital costs of wastewater treatment, and to allow treatment plants to expand treatment capacity incrementally without the need for additional space.



**A** **Conventional aeration processes pump air bubbles into the treatment tank via diffusers**



**B** **MABR technology feeds air or oxygen through a membrane tube at a low pressure**



## Suitability of WWTP sites for co-located hydrogen production

In November 2019, the COAG Energy Council's Hydrogen Working Group commissioned a report titled *Australian Hydrogen Hubs Study* which recommended criteria for domestic hub site selection.[6] As reflected in **Table 1**, WWTPs have the potential to meet many of these criteria. This overlap is largely a result of their prevalence across the country and the similarity in siting conditions for these facilities.

**TABLE 1**

*Recommended conditions for domestic hydrogen hubs according to the 'Australian Hydrogen Hubs Study' and a reflection of the suitability of WWTP sites.*

High compatibility | Moderate compatibility | Low compatibility

| Criteria Level 1 | Criteria Level 2 | Compatibility of WWTPs with criteria |
|---|---|---|
| **Production (green)** | **Renewable energy source** (High compatibility) | WWTPs increasingly have access to renewable energy, including behind the meter renewable energy generation. |
| | **Backup energy supply** (High compatibility) | The majority of WWTPs are grid connected because they are considered critical infrastructure. To ensure redundancy against power outages they typically operate back-up generators. |
| **Essential considerations** | **Transport access** (High compatibility) | WWTPs are typically located near urban centres with transport connectivity. |
| | **Gas transmission pipelines** (High compatibility) | Gas transmission pipelines are located around dense urban populations in order to cater for household and commercial gas use. WWTPs service similar customers and are often located in or near the same areas. Existing pipeline corridors also provide access to suitably zoned land. |
| | **Water access** (High compatibility) | WWTPs produce large volumes of recycled water each year, much of which is currently unused. |
| | **Health and safety provisions** (Moderate compatibility) | Hydrogen is a scheduled substance under current National and State workplace, health and safety legislation. Facilities storing it above specified limits are classified as a Major Hazard Facility (MHF) and subject to regulation. The MHF approval process includes rigorous health and safety assessments and establishing multi-layered controls, including buffer zones between the facility and nearby communities.<br><br>As a result of the environmental measures applicable to WWTP sites (see below), many have existing buffer zones that could benefit the siting of a hydrogen facility. However, this is an area that needs further consideration. |
| | **Environmental considerations** (High compatibility) | Hydrogen production is odourless and is unlikely to produce any more noise than the existing WWTP. Land owned by the water utilities is already zoned and approved for use by the existing business, so heritage and ecological sensitivity considerations are few. WWTPs are also typically well suited to manage any residuals produced by treating water to a quality suitable for use in electrolysis. |

| Criteria Level 1 | Criteria Level 2 | Compatibility of WWTPs with criteria |
|---|---|---|
| **Essential considerations** | **Economic and social considerations** | WWTPs are often located near urban centres. Co-locating hydrogen production could create local jobs and, if local mobility and industrial buyers transition to hydrogen, communities could benefit from additional energy security and avoided air and noise pollution.<br><br>From a social license perspective, safety is likely to be the biggest community concern and must be seriously considered. |
| | **Land availability** | Water utilities often buy additional land for future expansion purposes so that facilities can be scaled in response to population growth. If oxygen-based treatment can reduce the footprint of future expansions, already purchased land could become available for hydrogen production. However, decisions around land use should ensure that future treatment capacity growth is not negatively impacted. |
| **Demand** | **Population size and density** | WWTPs are often found near the outskirts of urban centres, close to major populations and the waste they produce. |
| | **Co-location with industrial ammonia production** | Some WWTPs are located near existing ammonia production facilities, for example Kwinana and Newcastle. |
| | **Co-location with future industrial opportunities** | There is potential for co-location with future industrial opportunities near WWTPs. This could include alumina production near areas such as Bunbury (WA). In the longer term, Australia's comparative advantage in alumina production could result in additional opportunities. |
| | **Proximity to export hubs** | Due to their prevalence across the country, many WWTPs are located near potential export hubs. |
| **Supply chain to domestic demand** | **Existing gas networks** | WWTPs and existing gas networks serve the same customers and are similarly located around the outskirts of urban centres. |
| | **Gaseous hydrogen storage** | Hydrogen storage will be required. Water utilities are familiar with handling and storing dangerous chemicals and flammable gases, such as methane. |
| | **Refueling stations** | Hydrogen is an emerging market and hydrogen refueling stations are rare. The Australian National Hydrogen Strategy recommends that existing infrastructure should be leveraged. This could include infrastructure around major logistic centres, where WWTP are often located. |

**Source:** Adapted from Table 11 in the 'Australian Hydrogen Hub Study', commissioned by the COAG Energy Council Hydrogen Working Group (2019).

Three site-selection conditions in particular improve WWTPs' suitability for hydrogen production by enhancing the value of existing or unused assets (**Figure 3**). These are land availability in proximity to demand, availability of recycled water, and access to on-site renewable energy.

## Condition 1: Land availability in proximity to demand

***Land availability:***

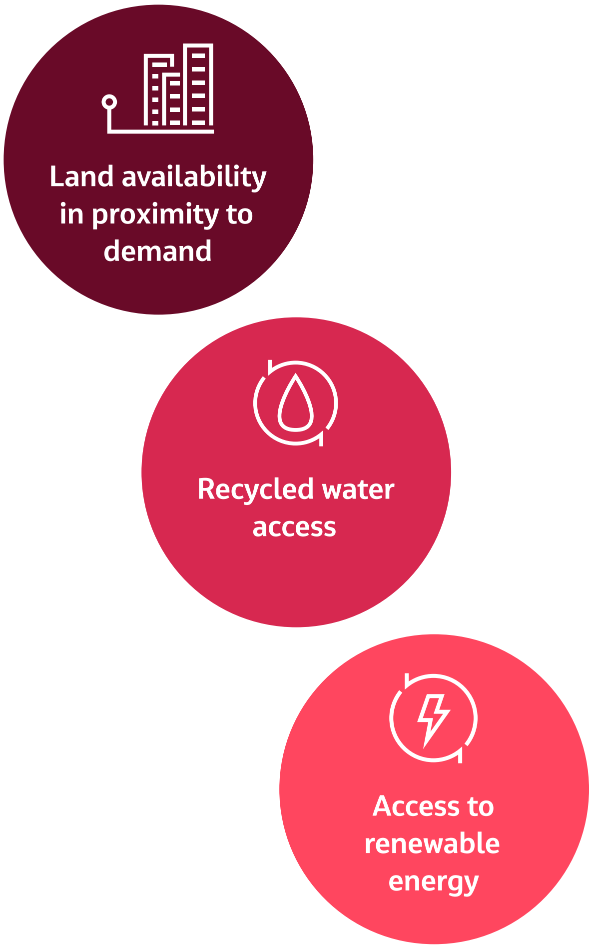
Many WWTPs have land reserved for future expansion. If the area of unutilised land is large enough, a portion could be made available to site a new hydrogen facility. Finding available land for a new hydrogen facility could also be supported by the use of more efficient oxygen-based treatment technologies which would reduce the WWTP footprint needed to accommodate future population growth.

***Proximity to demand:***

Hydrogen production facilities should be located near potential buyers in order to reduce distribution costs to these users. A proxy for assessing potential levels of demand is population density.[7] We can expect that large urban centres with a high number of dwellings and demand for transport would potentially generate a high level of demand for hydrogen. WWTPs are often found near the outskirts of large urban centres, close to the source of waste that they treat (see **Figure 4**).

**FIGURE 3**

*Three conditions may increase the suitability of co-locating hydrogen production at WWTP sites*




## Condition 2: Access to an abundant and sustainable source of water

It takes anywhere between 9 and 20 litres of water to make just 1 kg of hydrogen depending on the quality of the water source.[8] Readily available and reliable access to water is therefore critical for the development of hydrogen hubs. In our 2019 white paper *Australia's Pursuit of a Large Scale Hydrogen Economy*, we recommended the use of recycled water for hydrogen production for a number of reasons.[9]

- Recycled water is often treated to a standard suitable for the electrolysis process with minimal additional pre-treatment required.
- WWTPs produce billions of litres of recycled water each year and volume is consistent.[10]
- The use of recycled water does not compete with increasing urban demand for drinking water and will not adversely impact Australia's drinking water supply.
- Recycled water is less likely to be impacted in the event of an extended drought compared to desalinated and primary-use drinking water, which would be prioritised for human consumption.
- Right now, much of the recycled water produced is discharged back into the environment due to legislative and cost barriers that limit its use. Using recycled water for hydrogen production is unlikely to encounter these barriers and could even reduce the impact of WWTPs on local ecosystems that can be sensitive to changes in water chemistry and flow patterns.
- From a cost perspective, recycled water has been found to be less expensive than alternatives such as primary-use drinking water and desalinated water.[11]

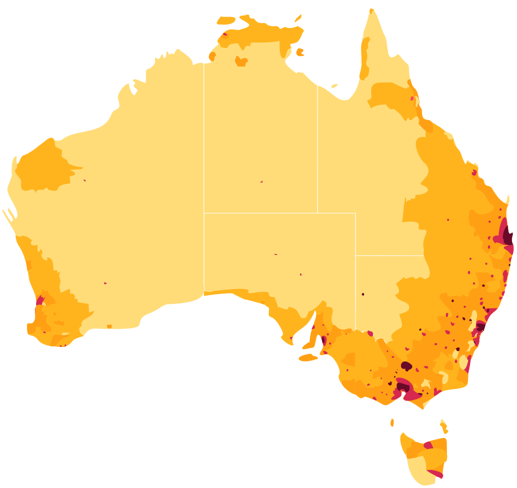
This presents an opportunity for water utilities to generate more value from recycled water by using it for hydrogen production.



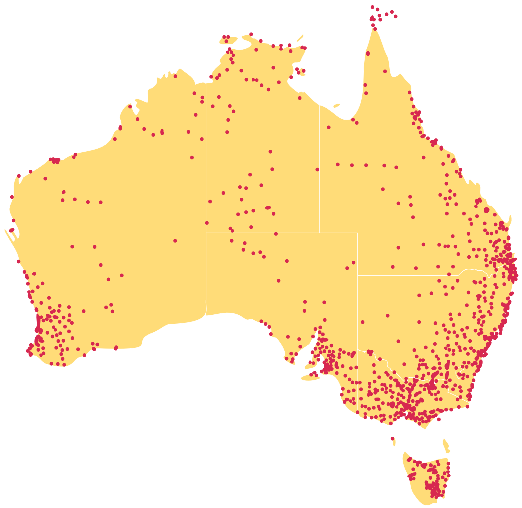
**FIGURE 4**

*Regional population density in Australia, 2016-17 relative to locations of wastewater treatment plants.*

**Population Density**



**Wastewater Treatment Plants**



**Source:** Adapted from Regional Population Growth, Australia, 2016-17, Australian Bureau of Statistics (2018). Retrieved from https://www.abs.gov.au/AUSSTATS/abs@.nsf/Previousproducts/3218.0Main%20Features702016-17 (Left); Hill, R, Carter, L, Kay, R. Wastewater Treatment Facilities, Geoscience Australia (2012). Retrieved from https://d28rz98at9flks.cloudfront.net/74625/WastewaterTreatmentFacilitiesMap_v1.jpg (Right).

## Condition 3: Access to renewable energy resources

Much of the water sector is already taking active measures to reduce emissions and a growing number of WWTPs have access to renewable energy from on-site generation. In fact, at some WWTPs, on-site renewable energy generation has begun to exceed energy usage, including at Melbourne Water's Western Treatment Plant[12] and Yarra Valley Water's Aurora Treatment Plant.[13]

Right now, excess renewable energy from WWTPs is typically fed back into the electricity grid. Although not necessarily a poor use of that energy, the electricity market in some Australian states is experiencing a heightened incidence of 'negative pricing' or constraints on exports to the grid (see **Figure 5**). This can occur when supply exceeds demand during certain times of day.

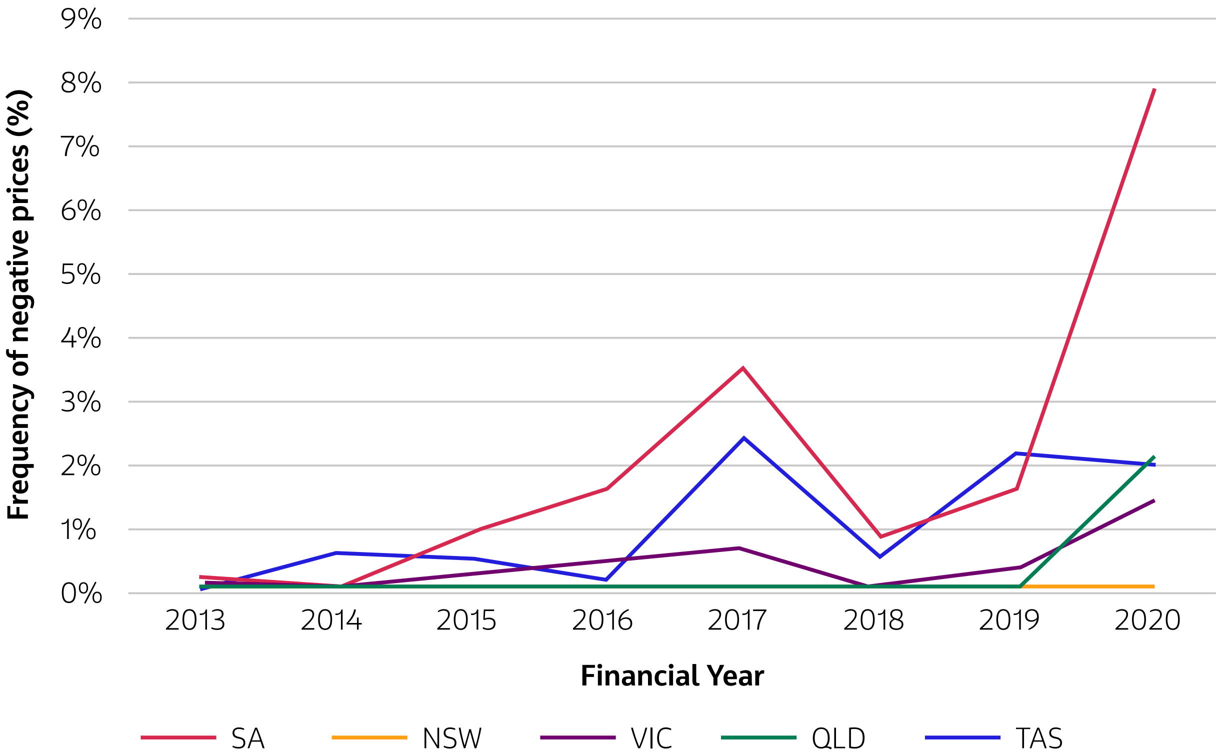
While future incidence of negative prices is uncertain, these trends can mean water utilities either generate a lower return, paying for the energy they export to the grid, or have their ability to export constrained rather than generating revenue.

Hydrogen production could enhance the value of renewable energy resources, helping water utilities scale up their renewable generation at WWTPs without exposing themselves to additional financial risk.



**FIGURE 5**

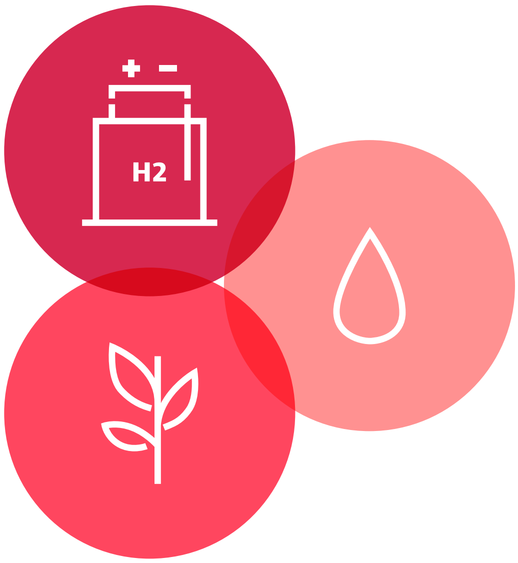
*The frequency of negative prices in half hourly trading periods have increased in recent years.*



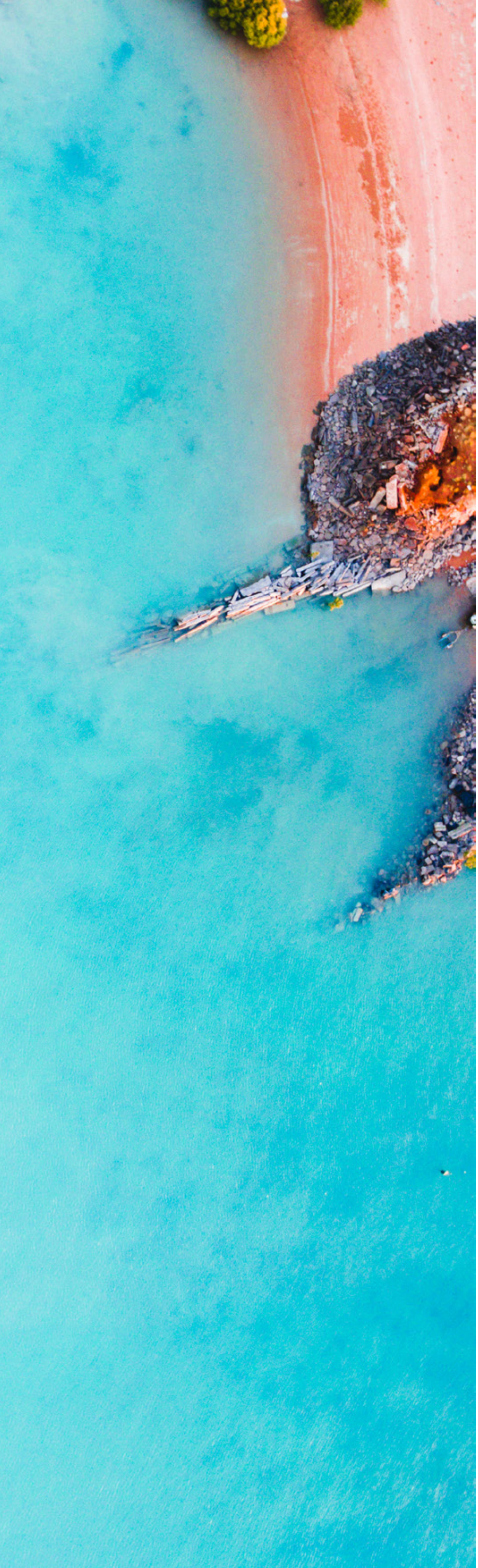

**Source:** Analysis by Jacobs. Note: 2020 represents year-to-date data as at May 2020.

## WWTPs as a facilitator of sustainable hydrogen production

The industry commonly refers to the potential of 'green', 'clean' or 'renewable' hydrogen, with the emphasis on the use of zero emissions energy. This terminology does not account for how the water required for the electrolysis process is sourced. Co-locating hydrogen production at WWTPs provides an opportunity to use recycled water as well as renewable energy. We refer to this as 'sustainable hydrogen', where hydrogen produced via electrolysis does not produce emissions or negatively impact Australia's water supply. This is particularly important given that water scarcity is a growing concern across the country.




> **Sustainable hydrogen will be the focus of our paper moving forward, unless otherwise stated.**



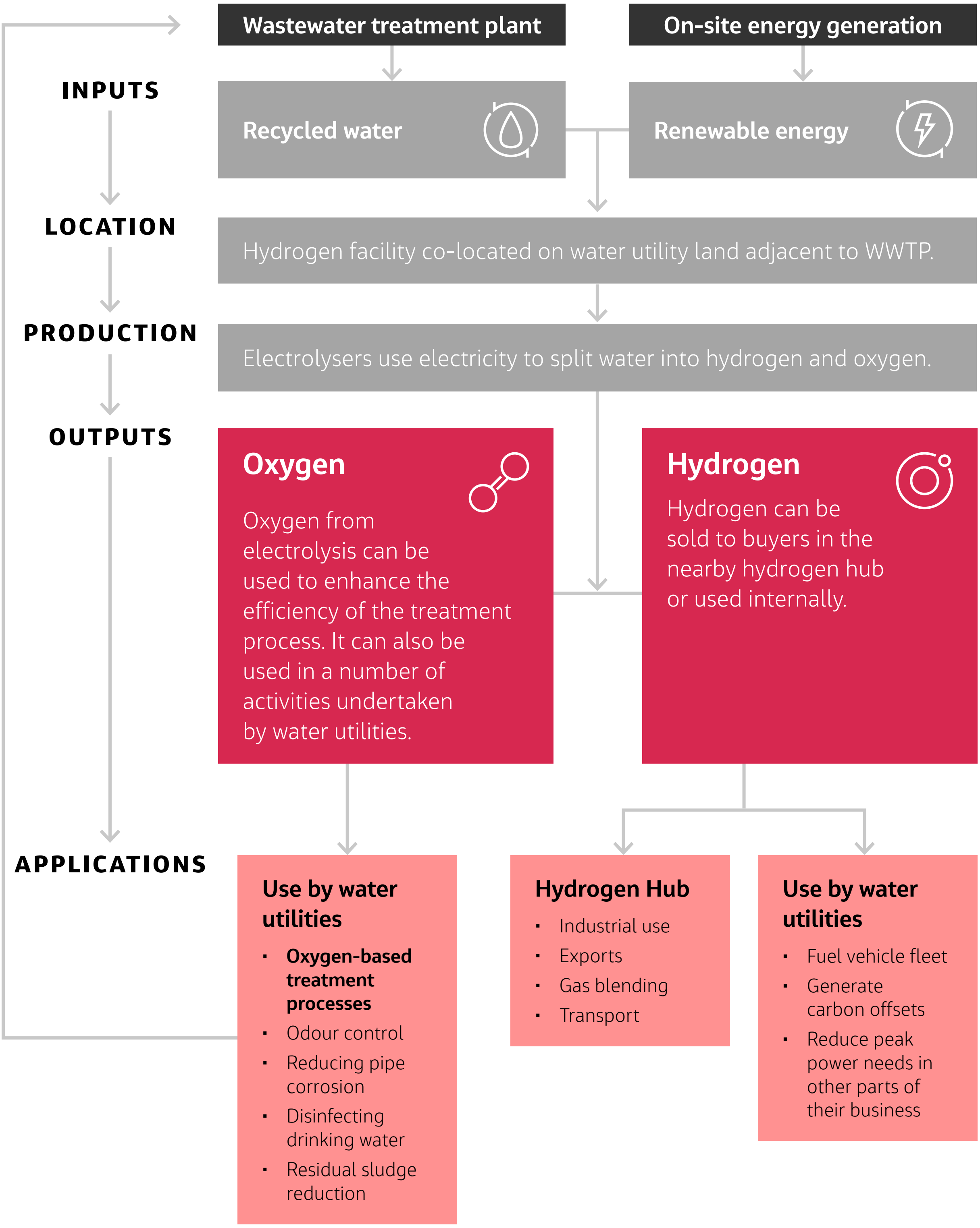
## **The purpose of our paper:** Assessing the commercial viability of co-located hydrogen production at WWTP sites

As outlined, many WWTPs meet the recommended site conditions for hydrogen hubs. Additionally, the potential to use pure oxygen in the treatment process could give value to what has traditionally been described as a 'by-product' of electrolysis. This represents an opportunity to partially subsidise hydrogen production and increase its commercial viability. Given these conditions, water utilities may have a pivotal role to play in accelerating the development of Australia's hydrogen industry by acting as a catalyst for hydrogen hubs (see **Figure 6**).

Our paper provides a high-level assessment of the potential benefit of transitioning to oxygen-based wastewater treatment and the impact that this would have on the commercial viability of hydrogen production. To improve the relevance of our results, Yarra Valley Water's Aurora wastewater treatment plant is used as a case study. This analysis will provide a better understanding of the conditions required to support co-located hydrogen production and will highlight the relevance of our results in the context of Australia's hydrogen strategy and the broader water industry.

**FIGURE 6**

*Reflection of WWTPs as the core of the sustainable hydrogen production process, rather than purely serving as a source of recycled water.*



CHAPTER TWO

# Our approach

The purpose of our high-level analysis was to assess whether co-locating hydrogen facilities at Wastewater Treatment Plants (WWTPs) could improve the commercial viability of hydrogen production. To improve the relevance of our study to the broader water sector, we have used Yarra Valley Water's (YVW) Aurora wastewater treatment plant (the Aurora WWTP) as a case study.

This is a preliminary assessment to facilitate broader discussion within the sector and assumptions regarding scale, timing and costs of future WWTP augmentations should be considered indicative.

# Case study justification

## Yarra Valley Water

Located in Wollert, Victoria, the Aurora WWTP consists of a sewage treatment plant and a recycled water treatment plant. The facility was constructed by 2006 and commissioned in 2009 to service a growing Melbourne population. The current facility was designed to meet the recycled water and sewerage needs of the new Aurora development, and other developments occurring in the Epping-Craigieburn growth corridor. The plant uses conventional aeration treatment technology to break down pollutants in the wastewater and has a treatment capacity of approximately 4 megalitres per day (MLD). The Aurora site has been identified by YVW as the most favourable location to further expand treatment capabilities in the growth corridor to meet future demand.

In line with the recommended conditions for hydrogen hubs outlined in the previous section, there are several conditions that make the Aurora WWTP site a suitable case study.

### Access to renewable energy

Renewable energy is readily available onsite. In 2017, as part of their emissions reduction objectives, YVW built a waste-to-energy facility ('ReWaste') adjacent to the Aurora WWTP.

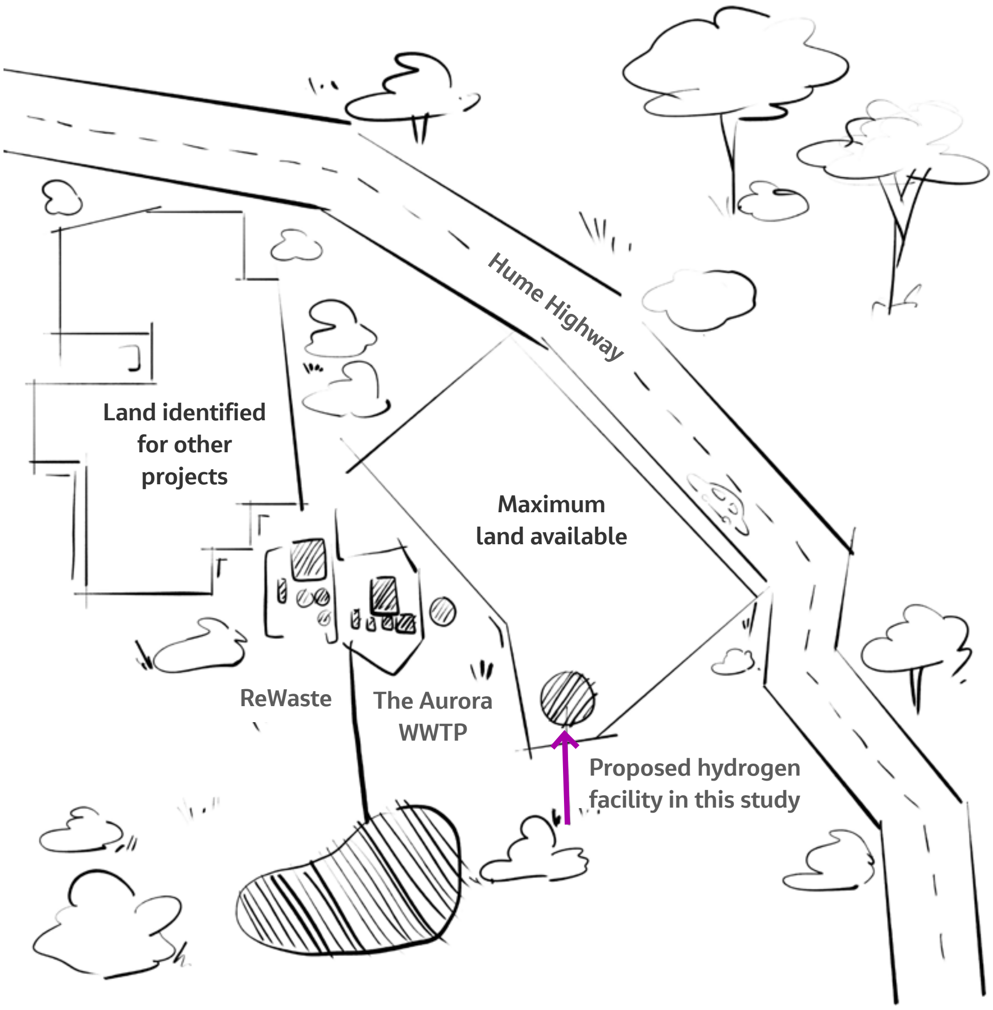
When operating at full capacity, it takes just 25% of ReWaste's generation to meet all of the Aurora WWTP's energy needs. The excess energy is currently exported to the electricity grid, but can be limited by network constraints. This excess generation from ReWaste could be redeployed for hydrogen production. As demand at the Aurora WWTP grows over time, a greater share of the renewable energy required for the hydrogen facility would need to be sourced from the grid unless there are plans to increase the capacity at the ReWaste facility. Grid augmentation may be required if a significant share of the electricity is sourced from the network. However, since the Aurora site is located in a growth corridor, it is likely that the network will need to be upgraded in future to accommodate expected population growth.

### An abundant supply of recycled water

The Aurora WWTP treats a large volume of wastewater every year and produces more recycled water than would be required for hydrogen production. Using the available recycled water would be a more sustainable low-cost option for a large-scale hydrogen industry compared to using existing or future drinking water resources.

**FIGURE 7**

*Potential location of a hydrogen production facility next to the Aurora WWTP and ReWaste*




**Note:** Diagram is for visualisation purposes only and does not indicate actual site location or reflect other planning considerations.

## Land availability

Located next to a major freeway on the outskirts of Melbourne, the Aurora WWTP sits on 160 hectares of land, 33 of which is utilised by existing operations. Part of the 95 hectares available for future use could be allocated to site a hydrogen facility.[i] The maximum size of the proposed hydrogen facility in our analysis is 12 MW. A facility of this size would use only 0.3% of the full capacity of YVW's current unutilised land, which could accommodate a facility of up to 4 GW (see **Figure 7**).

## Proximity to demand

Several potential buyers are located nearby, including a major gas transmission line, local bus operators and two municipal councils which operate waste disposal fleets that could be converted to fuel-cell vehicles in future.

YVW also has the potential to create internal demand for hydrogen to reduce greenhouse gas emissions and operating costs. This includes transitioning the vehicle fleet to fuel-cell vehicles and using hydrogen as a renewable energy source in other large YVW facilities located close to the Aurora WWTP.

i. The available land would be subject to native vegetation considerations.

## Demand for oxygen

The role of WWTPs in creating a stable market for oxygen is an unexplored opportunity to increase the commercial viability of hydrogen production.

The Aurora WWTP services a growing population and is currently approaching its treatment capacity. An initial 'Stage 1' major upgrade to replace the existing plant and more than double its treatment capacity from approximately 4 MLD to 10 MLD is expected in 2025.

A 'Stage 2' upgrade further increasing capacity from 10 MLD to 30 MLD is expected in 2035 (see **Table 2**). The designs have not been finalised, presenting an opportunity to assess whether incorporating pure oxygen from hydrogen production could be used in the wastewater treatment process to generate efficiency gains and cost savings.



**TABLE 2**

*Planned Aurora WWTP upgrades*

| | Estimated Timing | Total estimated treatment capacity (MLD) | Indicative costs for conventional treatment |
|---|---|---|---|
| Current WWTP | NA | 4 | NA |
| Stage 1 upgrade | 2025 | 10 | $60 million |
| Stage 2 upgrade | 2035 | 30 | $120 million |

**Note:** These are Jacobs' indicative estimates and represent a full plant replacement in Stage 1 and an upgrade in Stage 2 based on the needs of the current plant, and the projected population growth in the area.

# Scenarios, key assumptions and sensitivities

## Scenarios

Australia's hydrogen market is not yet established, and the potential demand and market price remain uncertain. Industry analysis indicates that demand for hydrogen will be generated if priced between $2-6/kg but it will take time for the market to grow and mature to a point where suppliers can be confident in securing purchase agreements for 100% of their product. The proposed hydrogen facility in our study was therefore built in two stages and sized to meet the oxygen demand from the Aurora WWTP. This allowed us to explore the extent to which a stable and growing demand for oxygen could effectively subsidise hydrogen production.

We assessed the commercial viability of co-locating hydrogen production at the Aurora WWTP using two scenarios which were compared against a business-as-usual case.

**SCENARIO 1**

*Hydrogen facility produces pure oxygen for Oxygen-based Conventional Aeration Treatment (OCAT).*

**SCENARIO 2**

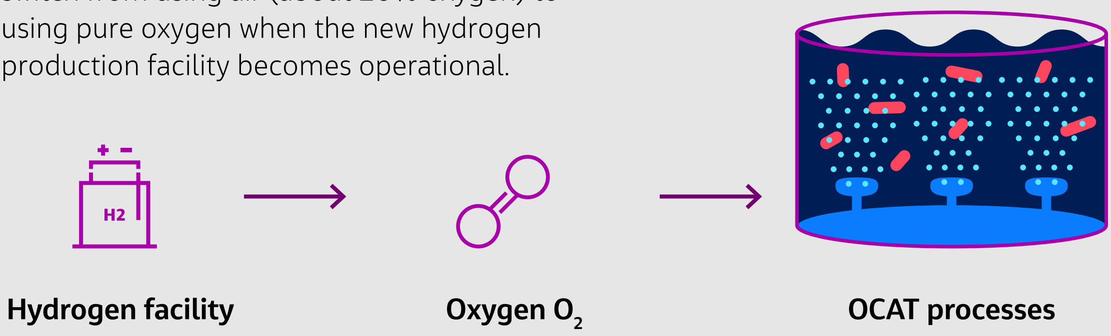
*Hydrogen facility produces pure oxygen for Oxygen-based MABR Treatment (OMT).*

**BUSINESS AS USUAL (BAU)**

## SCENARIO 1

A new hydrogen facility, built, owned and operated by YVW, is co-located at the Aurora WWTP and is operational by 2021. The Aurora WWTP will continue using existing diffused air treatment processes until the Stage 1 upgrade in 2025 but will switch from using air (about 20% oxygen) to using pure oxygen when the new hydrogen production facility becomes operational.

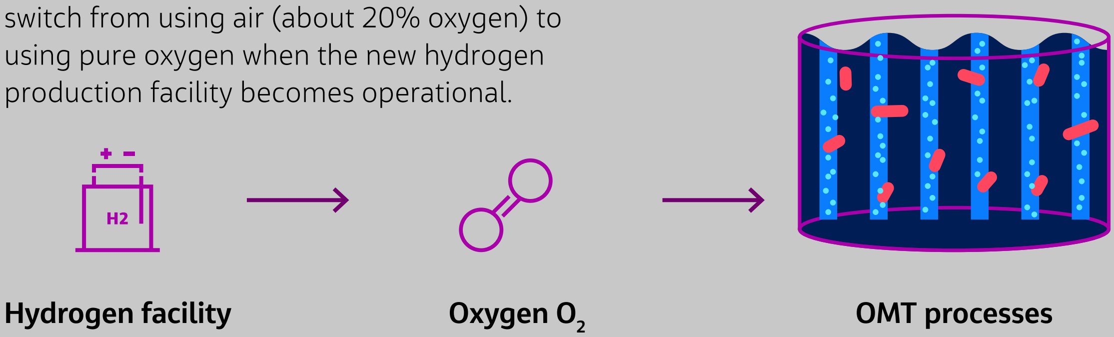
The Stage 1 and 2 Aurora WWTP upgrades will incorporate **OCAT processes** using oxygen produced from the co-located hydrogen facility.




## SCENARIO 2

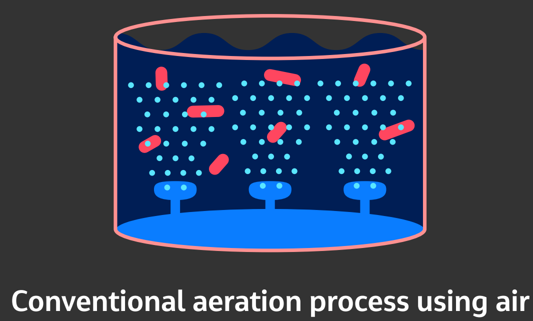
A new hydrogen facility, built, owned and operated by YVW, is co-located at the Aurora WWTP and is operational by 2021. The Aurora WWTP will continue using existing diffused air treatment processes until the Stage 1 upgrade in 2025 but will switch from using air (about 20% oxygen) to using pure oxygen when the new hydrogen production facility becomes operational.

The Stage 1 and 2 Aurora WWTP upgrades will incorporate **OMT processes** using oxygen produced from the co-located hydrogen facility.




## BAU

No hydrogen facility is built and operations continue as they are today. The Stage 1 and 2 Aurora WWTP upgrades continue using existing diffused air treatment processes. No high purity oxygen is used.



## Why we investigated oxygen-based treatment using both conventional aeration and MABR processes

Both OCAT and OMT processes are more effective at delivering oxygen to the micro-organisms in the treatment process than air. The increased efficiency from switching from air to pure oxygen will reduce energy consumption, require a smaller footprint for future upgrades and, in turn, reduce the WWTP's associated capital and operating costs relative to the planned BAU upgrades (see **Table 3**).

Unlike OMT, OCAT still relies on technology that uses fine bubble diffusion to deliver oxygen to the organic degrading bacteria in the wastewater. This is a less efficient process which requires double the amount of oxygen (compared to OMT). The savings in Scenario 1 (OCAT), whilst still significant, are therefore lower than those in Scenario 2 (OMT).

It is estimated that Scenario 1 will realise a capital saving of 15% and an energy efficiency improvement of 15% relative to BAU, while Scenario 2 will realise a capital saving of 30% and an energy efficiency improvement of 40% relative to BAU.

Despite the more modest savings of OCAT relative to OMT, we have considered it as a scenario in our analysis to simulate a situation where transitioning to other technologies, such as MABR, is not possible because of site-specific considerations.

## Assumptions and sensitivities

The commercial viability of the hydrogen facility for both scenarios was assessed over a 25-year period from 2020 to 2045.

The overarching assumptions which underpinned our assessment are as follows:

- The proposed hydrogen facility was built in two phases, increasing in size to align with the WWTP capacity and the oxygen demand at that capacity. The first phase was operational by 2021 and the second phase by 2035.
- Hydrogen production was directly aligned with oxygen demand at the Aurora WWTP and 100% of all oxygen produced was sold to the Aurora WWTP.
- The hydrogen facility sourced excess renewable energy from ReWaste. Where the hydrogen facility's total energy needs exceeded ReWaste's spare capacity, the facility sourced renewable energy from the grid.[ii] Note that any potential need for grid augmentation and/or an alternative expansion of the ReWaste facility was not modelled in this paper.
- Land was assumed to be available, and any costs associated with acquiring land were excluded from the analysis. Costs were included to account for site assessment and planning considerations.

A range of tests were conducted to assess the sensitivity of the results to some of the core assumptions used in the case study. The assumptions and the sensitivities tested are reflected in **Table 3.** A more detailed breakdown of the 19 sensitivity tests conducted is provided in **Appendix A**.



ii. This was achieved by surrendering one Large-Scale Generation Credit (LGC) created by ReWaste for every MWh of electricity purchased from the grid.

**TABLE 3**

*Base assumptions and sensitivities tested*

Base assumption

| Parameter | | Description | Low | Medium | High |
|---|---|---|---|---|---|
| Discount Rate | | The discount rate was based on YVW's Weighted Average Cost of Capital of 5%. Higher and lower discount rates were tested because discount rates vary across the sector, and for regulated and unregulated parts of the business. | 3% | 5% | 7% |
| Capital cost of hydrogen production | | Costs were based on current technology and market knowledge, and account for the full costs of project development. These are intended as indicative estimates as project costs can vary substantially depending on site specific factors and changes in technology as the market matures. To account for these uncertainties, a capital cost range of -50% to +50% was tested. | 50% | 100% | 150% |
| Revenue from hydrogen sold | Hydrogen sale price | The revenue generated was linked to two critical assumptions – the hydrogen sale price and the proportion sold. An average price of $4/kg was adopted for the base analysis but the price of the hydrogen would depend on its end use and can vary between $2/kg to $6/kg. This range was tested in the sensitivity analysis, noting that more demand for hydrogen could be generated when the price is more competitive (e.g. $2/kg). | $2/kg | $4/kg | $6/kg |
| | Proportion of hydrogen sold | Given the current maturity of the market, it is assumed that only 50% of the hydrogen produced is sold across the assessment period. This can be taken as an average, allowing for some ramp-up over time. As the potential future demand for hydrogen is uncertain, the analysis also tests the impact of halving and doubling the quantity sold. | 25% | 50% | 100% |
| Energy efficiency savings | | Energy efficiency improvements from adopting oxygen treatment processes at the Aurora WWTP are expected for both scenarios. The savings are expected to be approximately 15% for Scenario 1 (OCAT) and 40% for Scenario 2 (OMT). However, these savings will vary depending on the design and the technology adopted. Therefore, we tested an energy saving ranging between 10%-30% for Scenario 1 and between 20%-60% for Scenario 2. These ranges are considered relatively conservative. | 10% | 15% (OCAT) | 30% |
| | | | 20% | 40% (OMT) | 60% |

| Parameter | Description | Low | Medium | High |
|---|---|---|---|---|
| Capital cost savings | One of the key benefits of adopting oxygen treatment processes at Aurora WWTP is the lower capital cost of the planned upgrade. The improved efficiency of using oxygen along with some inherent benefits from the MABR process means a smaller footprint for a given capacity, resulting in lower capital costs. This is estimated at 15% for Scenario 1 and 30% for Scenario 2. However, the extent of these savings will depend on more detailed design and market testing. We therefore tested a range of 10%-30% for Scenario 1 and 20%-40% for Scenario 2. | 10% | 15% (OCAT) | 30% |
| | | 20% | 30% (OMT) | 40% |
| MABR membrane asset life | The membranes used in the MABR process in Scenario 2 were assumed to require replacement after 20 years. This was based on expected asset life from suppliers. However, given that insurance is only provided for 10 years, we also tested a sensitivity with a 10-year replacement schedule. | ~10 years | ~20 years | N/A |
| Inclusion of ACCU revenue | An Australian Carbon Credit Unit (ACCU) is a tradeable carbon offset with each credit representing one tonne of carbon dioxide equivalent ($CO_2e$) reduced. ACCUs can be created by demonstrating emissions reductions in a number of sectors. In the context of this study they were created by using the hydrogen produced in each scenario for two applications – as a substitute for emissions-intensive vehicle fuels and for injection into Victoria's natural gas network. These applications were selected based on likely demands near the proposed hydrogen facility in the near-term.<br><br>As a conservative assumption, potential revenue generated from ACCUs created have not been included in the analysis. While utilising hydrogen in different applications should be able to create ACCUs under various methods published by the Clean Energy Regulator, this is yet to be confirmed officially. To account for potential revenue, the sensitivity tests range from 0-100% of ACCUs sold. | 0% (base) | 50% | 100% |
| Electricity price for hydrogen production | The electricity required for hydrogen production was sourced from a combination of excess energy from ReWaste and 'green' electricity from the Victorian grid. Electricity prices were derived from Victorian time-weighted price projections conducted by Jacobs' Energy Markets team in January 2020. The average price for behind-the-meter generation from ReWaste over the 25-year assessment period was $68/MWh, which accounts for avoided Network Use of System (NUOS) fees. The average Victorian grid price for the same period was $100/MWh, which includes network fees and the cost of offsetting grid emissions so that the energy can be considered 'green'.<br><br>The price paid for electricity can greatly impact the overall cost of hydrogen production, and electricity markets can experience significant volatility. We therefore tested the sensitivity of the base results to a 30% decrease and a 50% increase in electricity prices. | 70% | 100% | 150% |

## Commercial viability analysis

For the Aurora WWTP to justify the decision to incorporate OCAT or OMT in its planned upgrades, the efficiency gains from these processes would have to outweigh the associated costs, including the cost of purchasing oxygen itself. At the same time, the hydrogen business must achieve a net present value (NPV) greater than zero from selling oxygen to the Aurora WWTP and the hydrogen to other buyers.

As both the regulated WWTP and proposed unregulated hydrogen businesses are part of the same parent company — YVW — overall commercial viability of co-located production at the WWTP was achieved where the NPV was positive for both entities.[iii]

The business structure is displayed in **Figure 8.**

Commercial viability was defined as an NPV greater than or equal to zero over a 25-year assessment period for each entity and was achieved:

- ***For the hydrogen facility:***

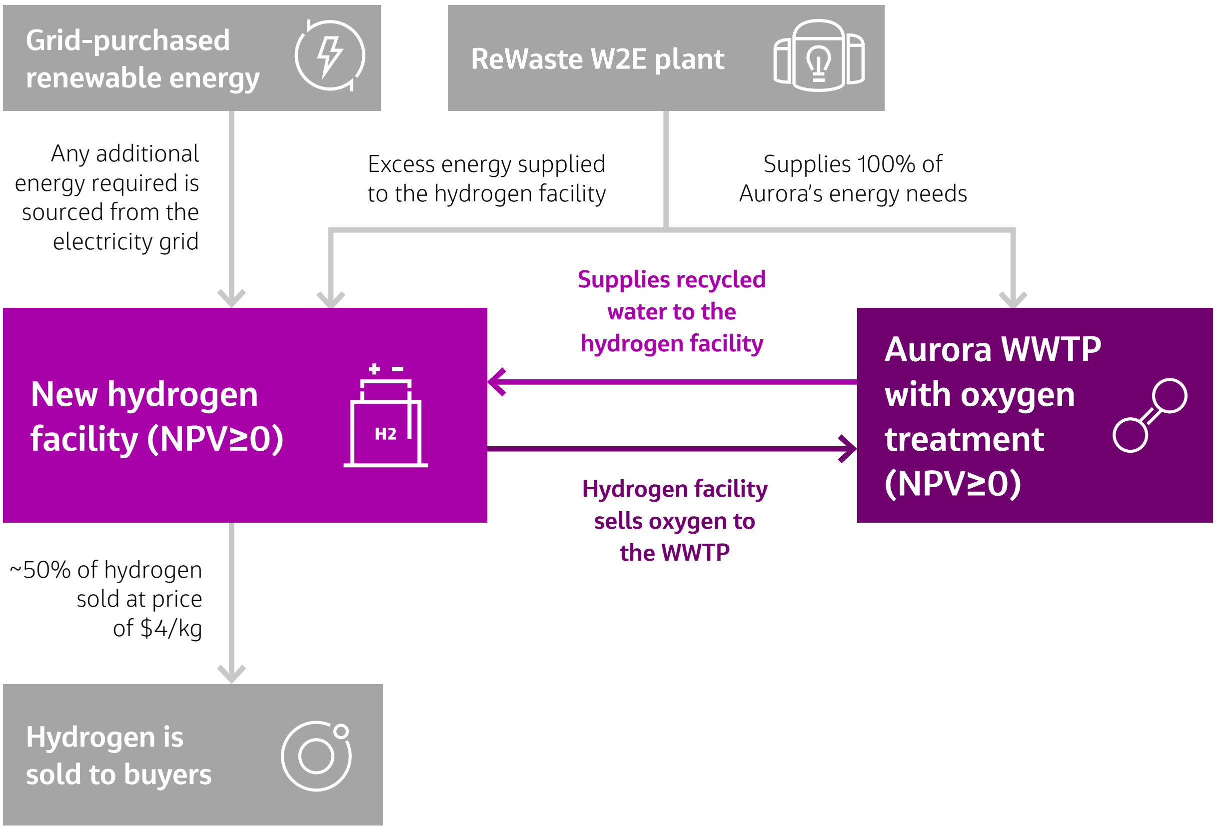
  Where the discounted revenue stream from selling oxygen and hydrogen was greater than the discounted costs associated with building and operating the plant.

- ***For the Aurora WWTP:***

  Where the discounted capital and operational cost savings from adopting oxygen-based treatment processes were greater than the discounted cost of oxygen.

**FIGURE 8**

*Reflection of the flows of costs and revenues between the proposed hydrogen facility, the Aurora WWTP and ReWaste.*




iii. NPV for the Aurora WWTP refers to a situation where incremental benefits are greater than the incremental costs of implementing oxygen treatment processes.

CHAPTER THREE

# Our results

The commercial viability of co-located hydrogen production at the Aurora WWTP was assessed via two scenarios. The results for each scenario are reflected in **Table 4.**

The proposed hydrogen facility was assumed to be operational by 2021 and was sized to meet the oxygen demand of the Aurora WWTP. The two scenarios considered reflect the different types of oxygen treatment which may be adopted as part of the Aurora WWTP's planned upgrade in 2025.

Scenario 1 was based on the adoption of oxygen-based conventional aeration treatment (OCAT) and Scenario 2 was based on the adoption of oxygen-based MABR treatment (OMT). Both scenarios assumed that 50% of the hydrogen was sold in the market at $4/kg.

**TABLE 4**

*Commercial viability results for both scenarios tested*

| | Scenario 1 | Scenario 2 |
|---|---|---|
| **Hydrogen facility** | | |
| Capital cost of the hydrogen facility* (present value) | $16.4m | $8.2m |
| Operating cost of the hydrogen facility (present value) | $54.4m | $26.4m |
| Revenue from sale of hydrogen (present value)** | $16.6m | $8.3m |
| Revenue from sale of oxygen | $16.1m | $26.3 m to $32.4m*** |
| NPV at hydrogen facility **** | -$38.1m | $0 to $6.1m |
| Price of oxygen where NPV at hydrogen facility = 0 | $0.82/kg | $0.79/kg |
| **The Aurora WWTP** | | |
| Cost of oxygen | $16.1m | $26.3m to $32.4m |
| Capital cost savings (present value) | $15.7m | $31.4m |
| Energy efficiency savings (present value) | $0.40m | $0.9m |
| Net Savings | $0 | $0 to $6.1m |
| Maximum price of oxygen where the benefits of oxygen-based treatment at the Aurora WWTP outweigh the costs***** | $0.24/kg | $0.98/kg |

* The hydrogen facility was sized to meet oxygen demand and built in two stages

** Assuming 50% of the hydrogen is sold at a price of $4/kg

*** This range reflects that oxygen could be sold for a minimum of $0.79/kg for the hydrogen facility to break even and a maximum price of $0.98/kg.

**** At the maximum NPV, the net benefit at the Aurora WWTP is zero – i.e. the cost savings equal the additional cost of oxygen.

***** This price of oxygen is the 'break-even' price of oxygen. It is higher in Scenario 2 than in Scenario 1 due to the higher capital cost and energy efficiency savings realised when implementing OMT processes.

## Scenario 1 results

Under Scenario 1 (OCAT) the hydrogen facility was not commercially viable, producing an NPV of -$38.1 million over the 25-year assessment period. A larger sized facility was required to supply enough oxygen for the less efficient OCAT process, but the higher costs associated with this effort could not be offset by the revenue from the sale of hydrogen and oxygen. In addition to needing to sell much larger volumes of hydrogen, the hydrogen facility was not able to sell oxygen at its 'break-even' price of $0.82/kg because the Aurora WWTP would not be willing to pay more than $0.24/kg for oxygen. If it did, the costs of adopting OCAT would outweigh the relatively modest savings achieved.

## Scenario 2 results

Under Scenario 2 (OMT), the hydrogen facility was commercially viable where oxygen was sold to the Aurora WWTP at anywhere between $0.79/kg and $0.98/kg, achieving an NPV of up to $6.1 million over the 25-year assessment period.

Where oxygen was sold for less than $0.98/kg, the capital and energy cost savings of $32.4 million realised by the Aurora WWTP from adopting OMT outweighed the costs of buying oxygen.

Taken together, these results indicate that the $6.1 million in potential net benefits could be shared between the Aurora WWTP and the hydrogen facility, thereby achieving commercial viability for both entities.

## Sensitivity results

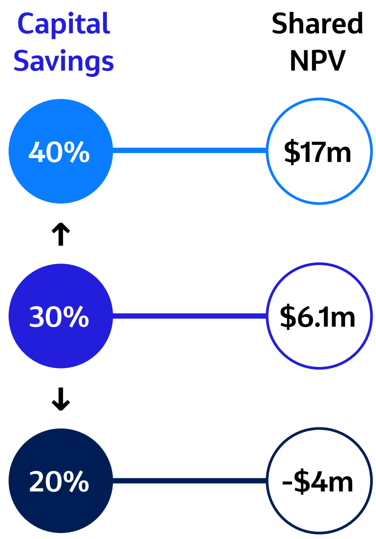
To test the robustness of these findings, we ran 19 sensitivity tests where we altered over ten variables (see **Appendix A**). The shared NPV in Scenario 1 remained negative for all sensitivity tests, even when all the hydrogen produced was sold at the higher price of $6/kg. Selling hydrogen for more than this price would limit the number of potential buyers and substantially increase project risk.

For Scenario 2, the shared NPV remained positive when altering the majority of variables. Interestingly, the sensitivity testing revealed that the hydrogen facility was commercially viable when 50% of the hydrogen produced was sold at a price of $2/kg and oxygen was sold between $0.92/kg and $0.98/kg. $2/kg is the price target the Australian Government considers necessary for hydrogen to compete with alternative storage technologies in our energy system.

However, Scenario 2 was highly sensitive to two factors — capital cost savings and the cost of electricity.

### *Capital cost savings*

Without changing any other assumption, when savings were reduced from 30% to 20%, the shared NPV fell from $6.1 million to about -$4 million. Conversely, when savings were increased from 30% to 40%, the NPV increased from $6.1 million to about $17 million.




This indicates that the results are dependent on the assumption that OMT can deliver increased efficiency gains compared to existing treatment processes by reducing the footprint and associated capital costs. It also highlights the importance of validating these assumptions through detailed technical due diligence and feasibility studies.

### *Cost of electricity*

To produce the amount of oxygen required to meet the Aurora WWTP's future needs, the hydrogen facility required more energy than could be supplied by the excess from ReWaste, and additional energy had to be sourced from the electricity grid.[iv] When the cost of electricity was increased by 50% from an average of $90/MWh to $135/MWh, the NPV decreased to -$5.1 million. Conversely, when the cost of electricity decreased from an average of $90/MWh to $63/MWh, the NPV increased to $12.8 million.

| Electricity cost | Shared NPV |
|---|---|
| $ ↑ from $90/MWh to $135/MW | ↓ **-$5.1 million** |
| $ ↓ from $90/MWh to $63/MWh | ↑ **$12.8 million** |

Electricity prices in the National Electricity Market can experience significant volatility, with annual average prices over the last four years ranging from $70 to $110/MWh. To minimise the risk of price volatility, it may be prudent to enter into hedging arrangements or long-term renewable power purchase agreements which set a fixed price for the duration of the contract.

iv. This included the cost of offsetting emissions from any electricity purchased to ensure that the hydrogen produced could still be considered zero-emissions.

# The commercial viability of the hydrogen facility was dependent on the guaranteed sale of oxygen

Under Scenario 2 (OMT), the cost savings for the Aurora WWTP resulted in a guaranteed demand for oxygen at a price of up to $0.98/kg. This made the hydrogen facility commercially viable while selling hydrogen at a competitive price.

**Figure 9** shows the relationship between the percentage of oxygen sold and the required sale price of hydrogen for the hydrogen facility to be commercially viable.

When 100% of the oxygen was sold to the Aurora WWTP at a negotiated price of $0.88/kg — the mid-point between the lower and upper bound of the oxygen price that delivers a benefit for both entities — the hydrogen facility was commercially viable when just 50% of the hydrogen was sold for $2.70/kg.

If 100% of the hydrogen was sold, it could be priced as low as $1.35/kg and the hydrogen facility was still commercially viable. This is lower than the price target set by the Australian Government for hydrogen to be competitive at scale.

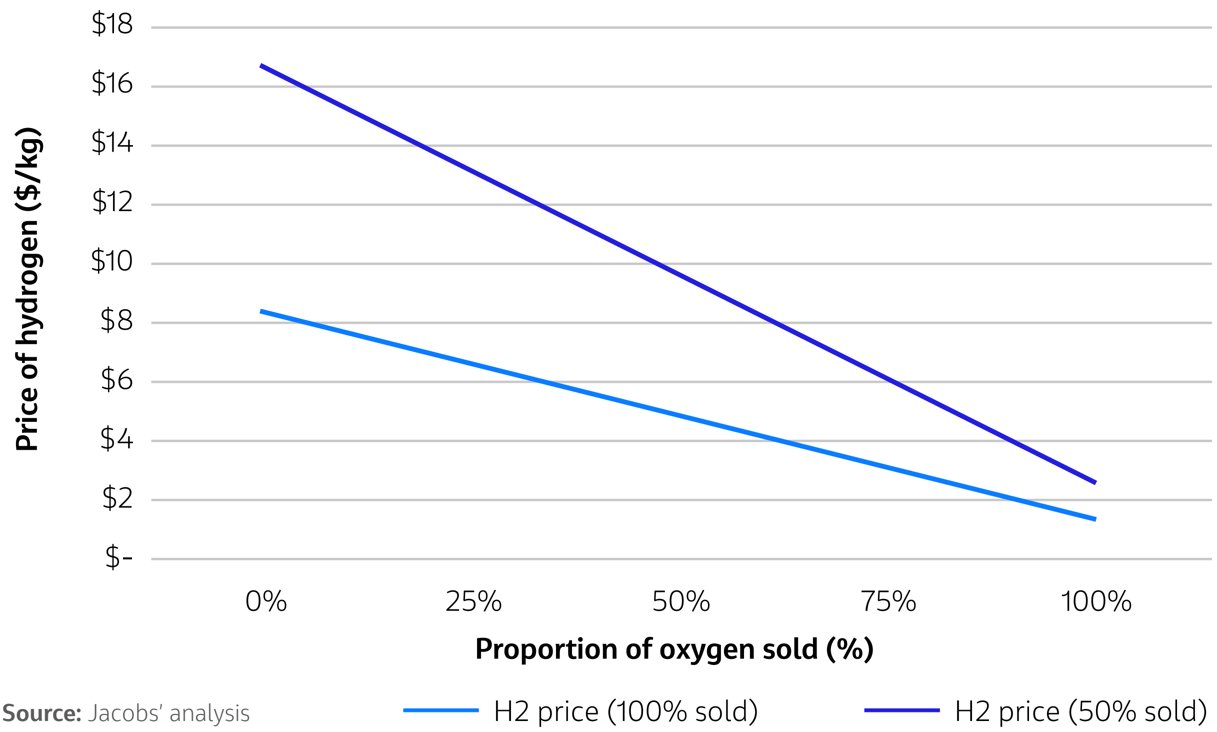
If none of the oxygen was sold from the hydrogen facility, the hydrogen needed to be priced between $8.30/kg if 100% was sold, and $16.70/kg if 50% was sold. Both prices are well above the competitive price range between $2-6/kg and finding a demand for hydrogen in this price range could prove difficult.

These findings demonstrate the extent to which the commercial viability and competitive advantage of hydrogen production could be supported by the guaranteed sale of oxygen to WWTPs.



**FIGURE 9**

*The extent to which hydrogen price is influenced by the guaranteed sale of oxygen (at $0.88/kg).*




**Source:** Jacobs' analysis

# Finding the 'middle ground' so that net benefits can be shared

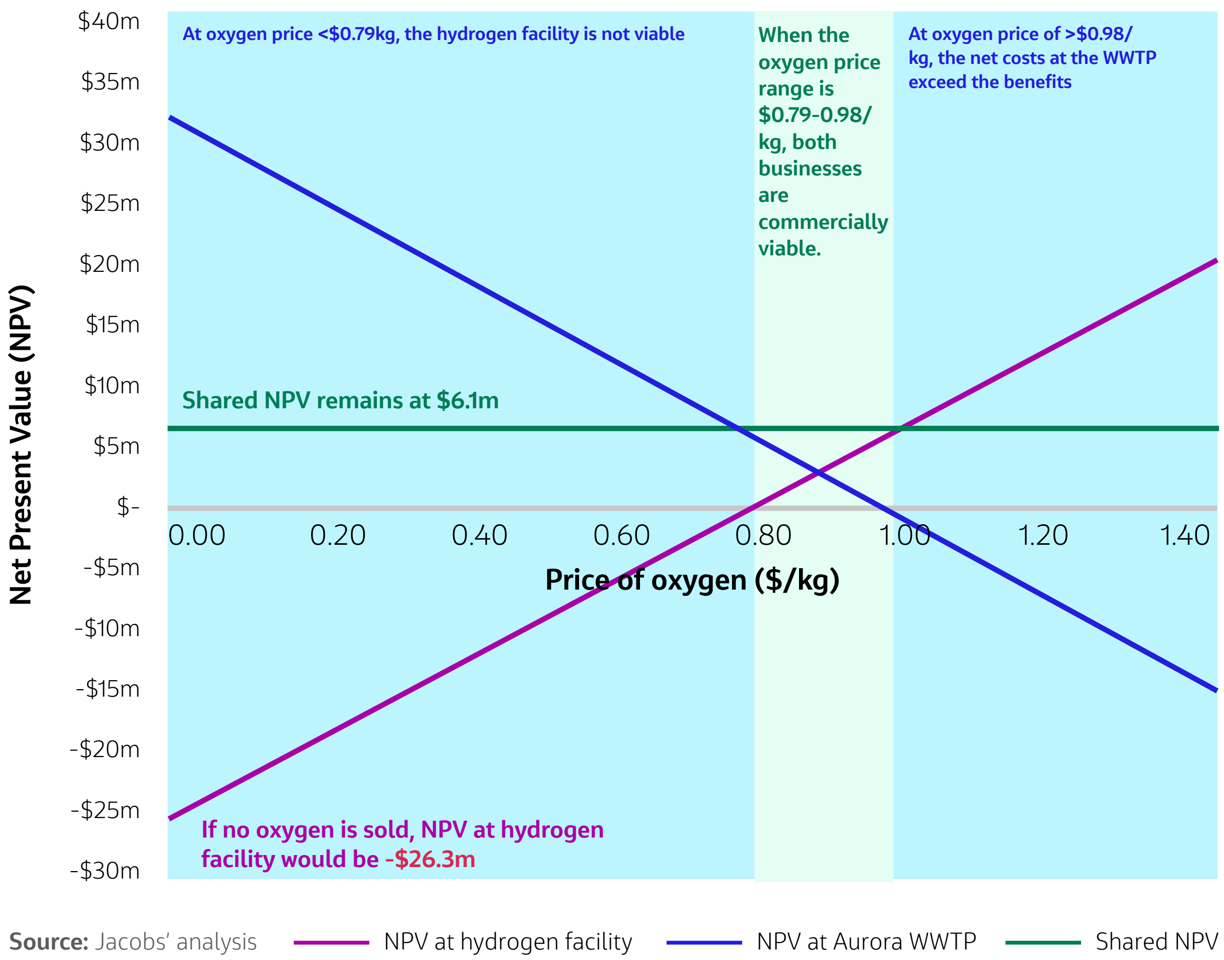
The Aurora WWTP case study illustrates how water utilities like YVW are in a unique position to benefit from the relationship between oxygen and hydrogen in the form of greater flexibility over the shared benefits if they own and operate both facilities.

For the purpose of this case study, we assumed both the regulated Aurora WWTP and the unregulated hydrogen facility would operate under the same parent company (YVW).

**Figure 10** shows the relationship between oxygen price and NPV for both the WWTP and hydrogen facility when implementing OMT processes (Scenario 2). The lower bound oxygen price of $0.79/kg would see all the benefit go to the WWTP and the upper bound price of $0.98/kg would see all the benefit go to the hydrogen business. Ideally, the agreed price would sit somewhere in between these bounds so that the hydrogen facility can be compensated for taking on a greater share of risk and the water business can pass commercial savings on to its customers.

**FIGURE 10**

*Relationship between oxygen price and NPV for the WWTP and the hydrogen facility. This chart reflects our base assumptions where only 50% of the hydrogen was sold at a price of $4/kg and 100% of the oxygen was sold.*




**Source:** Jacobs' analysis

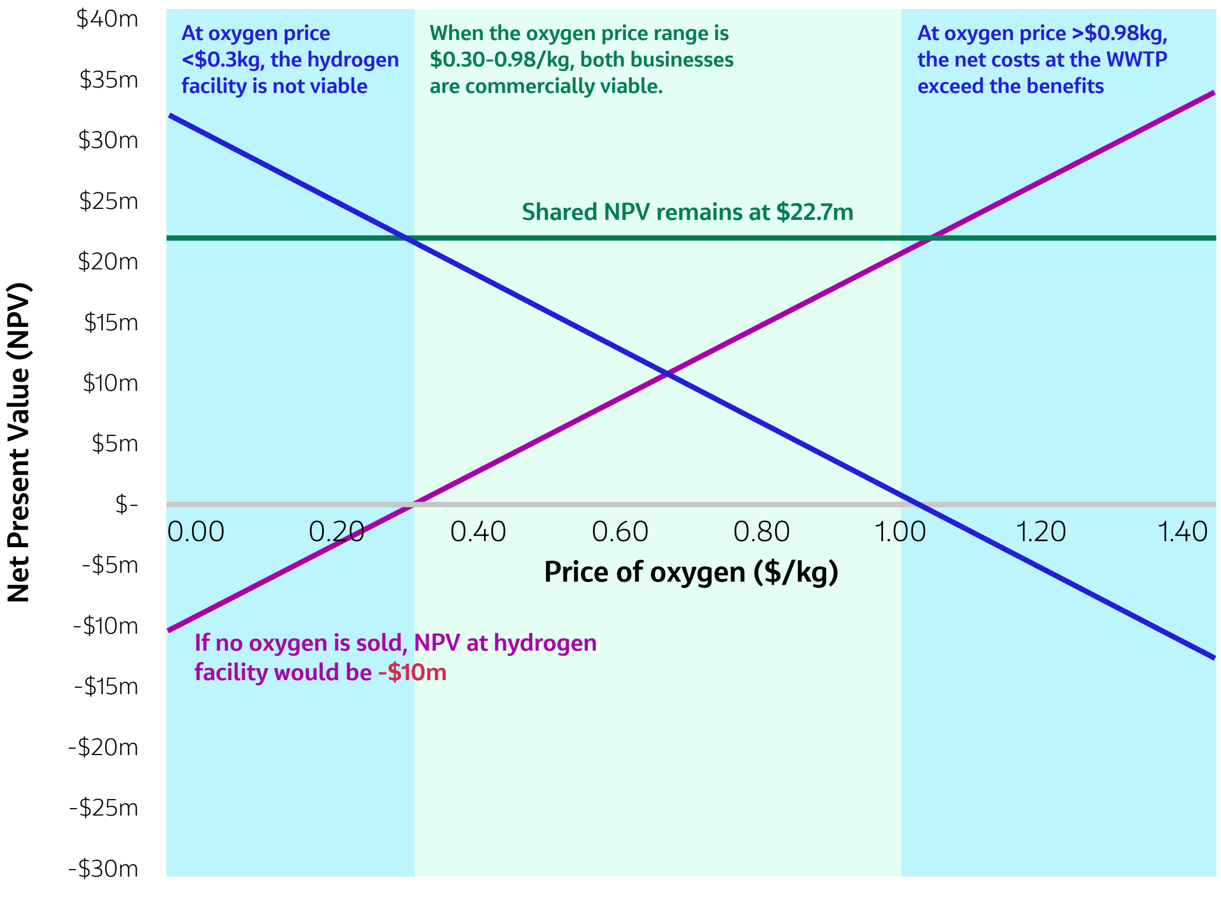
As the relationship between the hydrogen and oxygen price is interdependent, it is important to consider how the price of oxygen might vary if a higher proportion of hydrogen was sold at a higher price.

**Figure 11** shows how the range of shared benefits could increase if 100% of the hydrogen was sold at $6/kg. This is the upper price range identified as viable for certain buyers, including medium to large-scale mobility applications.

Under these conditions, the hydrogen facility would be commercially viable if oxygen is sold at a price above $0.30/kg. If the oxygen price is between this lower bound and $0.98/kg, the shared benefit between the WWTP and the hydrogen facility is estimated at $22.7 million. If no oxygen is sold, the hydrogen facility would not be commercially viable, and the net present cost would be $10 million.

**FIGURE 11**

*Relationship between oxygen price and NPV for the WWTP and the hydrogen facility. This chart assumes that 100% of the hydrogen was sold at a price of $6/kg and 100% of the oxygen was sold.*




**Source:** Jacobs' analysis

CHAPTER FOUR

# Significance & implications

Our paper set out to provide a high-level assessment of the potential benefit of transitioning to oxygen-based wastewater treatment and the impact that this would have on the commercial viability of co-locating hydrogen production at wastewater treatment plants (WWTPs).To improve the relevance of our results, Yarra Valley Water's (YVW) Aurora wastewater treatment plant (the Aurora WWTP) was used as a case study.

## Summary of results

Our results suggested that co-locating hydrogen production at the Aurora WWTP could be a mutually beneficial arrangement for both the WWTP and hydrogen facility under the conditions modelled in Scenario 2. Replacing current treatment processes with oxygen-based MABR treatment (OMT) resulted in substantial capital and energy cost savings for the Aurora WWTP. In turn, this created a stable and growing demand for oxygen, providing a second potential revenue stream for the hydrogen facility. This secure revenue stream allowed for the hydrogen to be sold at a competitive price without sacrificing commercial viability. Importantly, this would reduce the risk for early entrant hydrogen suppliers.

Our results also showed the interdependence between the price of hydrogen, the price of oxygen and the volumes sold. With the Aurora WWTP and the hydrogen facility in the case study owned by the same parent company, there was an opportunity for greater flexibility around sharing the benefits between the two businesses. This is important in the context of the emerging status of Australia's hydrogen industry where it may be beneficial for the hydrogen facility to negotiate a more flexible oxygen price contract with the Aurora WWTP. For example, this could be achieved through an arrangement that would see the oxygen price being reduced as the hydrogen market matures. In the short term, this would allow more of the benefits fall to the hydrogen facility, and in the longer term, more savings would be realised by the WWTP.

Given the conservative nature of some of our core assumptions and the sensitivity ranges tested, the results are promising. Energy savings from MABR technology are likely to be greater than those assumed, and the cost and efficiency of electrolyser technology is continuously improving. Including these changes would likely increase the viability of our findings. Looking ahead, more detailed technical and commercial feasibility studies are needed to ensure that a range of scenarios are considered and the full scope of potential outcomes are understood.

# Implications for Australia's hydrogen strategy

It is important to consider these findings in the context of Australia's hydrogen strategy and how they apply to the broader water industry. Based on our case study results, Scenario 2 was the only commercially viable option.

**From this point forward, when we refer to the benefits of 'oxygen-based treatment', we are referring to the conditions met under Scenario 2.**

This decision will depend on several factors, including how quickly technology costs fall and the extent to which local buyers can integrate hydrogen into their operations, either for new operations or as a substitute for other fuels.

Given the modular nature of electrolysis technology and the ease with which it can be scaled, the timing and sizing of project expansions are flexible and water utilities can determine how to best co-optimise developments between future oxygen needs and the evolution of the hydrogen market.

## 1

### Co-located hydrogen production at WWTP sites could act as a catalyst for hydrogen hub developments

With the secure demand for oxygen from WWTPs effectively subsidising the cost of hydrogen production, the resulting ability to sell sustainable hydrogen for a competitive price could support more rapid development of hydrogen hubs. To put this opportunity in perspective, the average yearly supply of the hydrogen produced in our case study would be enough to fuel approximately 50 full size buses, the size of fleet which could provide a scheduled route service for a town with a population of approximately 50,000 to 100,000 people. An initial cluster of buyers at this scale would help to catalyse the development of hydrogen hubs and in turn, support the creation of hydrogen-related enabling infrastructure and reduce barriers to uptake.

Beyond serving as an initial catalyst for hydrogen uptake, decisions around whether to scale a project beyond the oxygen needs of a WWTP should also be considered.

## 2

### A best-practice process repeated regionally would allow hydrogen demand and infrastructure to scale beyond local applications and support inter-state and international supply chains

Aging infrastructure, emissions reduction targets and the need to cater for growing populations means many of Australia's WWTPs are looking to upgrade or increase their capacity. If a number of strategically located WWTPs are considering a transition to oxygen-based treatment and are also open to co-located hydrogen production, this could support the development of a network of WWTP-based hydrogen hubs across Australia. This is an important step in creating a mature hydrogen market by encouraging earlier adoption and attracting additional suppliers. Sites located near ports, transport corridors, and inter-state logistics operations would carry more strategic value as they are ideal locations for future critical supporting infrastructure, including major re-fuelling stations and export terminals that will be required as part of a large-scale hydrogen industry in Australia.

## 3

## Co-located hydrogen production at WWTPs could support the Australian Government's 'H2 under 2' economic target

If the results of our study can be replicated, the revenue generated by supplying oxygen to WWTPs could be substantial enough to allow hydrogen to be sold at a price of under $2/kg if necessary. To highlight the significance of this in the context of Australia's domestic market, achieving a price below $2/kg effectively equates to a diesel price of less than $0.60 per litre. This would provide an economically viable pathway to reducing transport sector emissions.

Meeting this price target would mean that hydrogen could also be used in domestic applications that were previously considered longer-term opportunities. For example, several of Australia's major coal-fired generators are expected to close within the next 15 years, which could lead to a higher risk of supply shortfalls.[14] Faster adoption of hydrogen as a form of long-duration energy storage for the electricity grid and back-up power could prove especially useful as a means to support the electricity system through this transition.

## 4

## An alternative approach to project funding

Over $300 million dollars of funding and low-cost loans for hydrogen projects have recently been made available and grant providers are faced with the difficult task of prioritising resources towards initiatives that have the greatest potential. When reviewing future funding strategies, it is worth considering whether redirecting funding towards a faster transition to oxygen-based treatment as part of an overall hydrogen strategy could be more cost-effective.

# Implications for water utilities

## 1

### Cost savings from oxygen-based treatment

The opportunity to use oxygen in certain wastewater treatment technologies to generate net savings suggests that it should be considered in future WWTP designs. Oxygen-based treatment has potential to reduce the capital costs of new treatment plants or upgrades to existing plants. It could also improve the energy efficiency of wastewater treatment and help decarbonise an industry that is responsible for approximately 2% of global emissions.[15]

## 2

### Oxygen supply could be scaled for additional beneficial applications

If hydrogen facilities are scaled in-line with a growing hydrogen market, the additional oxygen produced could be used in other beneficial water industry applications. This may include replacing chemical salts (thereby reducing pipe corrosion), disinfecting recycled and drinking water and controlling odour. Oxygen is also effective at stabilising and reducing residual sludge, the by-product of treatment processes, which is expensive and difficult to dispose of. Using oxygen in these applications could represent additional cost savings for water utilities.

## 3

### New revenue streams

Selling hydrogen and oxygen would generate new revenue streams for the unregulated subsidiaries of water utilities. In our case study, the net revenue generated by the hydrogen facility from the sale of 50% of the hydrogen and 100% of the oxygen produced ranged from approximately $362,000 in 2025 to $1.6 million in 2045.

Converting constrained or underutilised on-site renewable energy generation and recycled water into a higher value product would also increase revenue from water utilities' existing operations.

## 4

### Alignment with sustainability goals

Many water utilities have identified sustainability goals and set emission reduction targets. In Victoria, water utilities have a target of net-zero emissions by 2030. Right now, meeting this goal is likely to require the creation of carbon offsets such as Australian Carbon Credit Units (ACCUs) because some sources of emissions at WWTPs are too difficult to eliminate directly. As we approach net zero targets, water utilities will need thousands of these credits to offset these emissions and costs are significant. ACCUs have been trading between $15 to $17 per tonne of $CO_2e$ in recent years, with an expectation that prices will rise in future years in line with the collective ambition to reduce emissions.

Co-located hydrogen production and the type of treatment technology used in our case study (MABR) could help water utilities achieve their emissions targets in two distinct ways:

- ***Creating ACCUs:***

  Producing hydrogen can create ACCUs in several ways, including when it is used as a replacement for emissions-intensive fuels such as petrol and diesel. In the context of water utilities, selling hydrogen to replace diesel fuel in vehicles would have the dual benefit of eliminating direct emissions from these vehicles while also creating ACCUs for the water utility.

These credits could then be used to offset emissions from other parts of the water business. Water utilities may need to acquire the ACCUs at market value but, assuming the hydrogen facility was owned by the unregulated subsidiary of the parent company, they would effectively be buying the credits from themselves.

- ***Eliminating direct emissions:***

  In addition to the energy efficiency improvements of using oxygen in treatment processes, the use of MABR technology itself also offers an opportunity to reduce or eliminate some direct emissions. For example, nitrous oxide is a greenhouse gas considered to be 300 times more powerful in its atmospheric warming effect than carbon dioxide.[16] Implementing MABR treatment could help to eliminate these emissions, meaning that water utilities would need to invest less in projects that generate ACCUs to meet their targets.

# 5

## Community wellbeing

Expectations around the roles and responsibilities of water businesses are changing - not only regarding how they deliver essential water and sanitation services, but also their impact on the wellbeing of the communities they serve and society more broadly. Reducing the price of hydrogen and encouraging adoption by nearby users, such as council waste collection vehicles, would directly contribute to improved air quality and reduced noise pollution for local communities. Additionally, the smaller footprint required for pure-oxygen treatment means some unutilised land could be freed up and repurposed for initiatives that contribute to greater community or environmental wellbeing, for example replanting native vegetation.

CHAPTER FIVE

# Future considerations

**The results presented in this paper highlight the need for more detailed technical and commercial analysis to validate the potential for site-specific benefits of co-locating hydrogen production at wastewater treatment plants (WWTPs). To support this, a number of considerations should be explored in more detail.**

# The success of co-locating hydrogen at WWTPs will be influenced by two key factors

A key consideration for developing WWTP-based hydrogen hubs is whether the commercial benefits realised for both the hydrogen facility and the Aurora WWTP in our case study can be replicated for other sites. Each treatment plant will face different conditions and potential cost savings. As our sensitivity analysis shows, there are a number of conditions that could influence these outcomes. Two primary factors are whether a WWTP is due for an upgrade and whether it has access to low-cost renewable energy generation.

## 1

## Planned WWTP infrastructure replacements or upgrades

Our case study shows that favourable commercial outcomes are likely if WWTPs transition to oxygen-based treatment when due for replacement. Further analysis is needed to explore the commercial viability for smaller upgrades or early refurbishments for WWTPs not yet due to be replaced.

While our paper examines using oxygen produced during the hydrogen production process to upgrade WWTP processes, the oxygen could be used for other water industry applications as mentioned earlier in this paper. If energy efficiencies and capital cost saving are not enough to support commercial viability for transitioning to oxygen-based treatment for smaller upgrades or early refurbishments, the benefit of these other applications could be investigated in more detail.

## 2

## Access to low-cost zero-emissions energy

Our study suggests that electricity prices are one of the major drivers of sustainable hydrogen project costs, so options for sourcing cost-effective, zero-emissions electricity should be evaluated. Although the scenarios tested in our study used a combination of excess energy from an on-site waste-to-energy plant and renewable electricity from the grid, organising low-cost electricity supply arrangements will vary considerably depending on site specifics and project scale. With this in mind, options worth considering are:

- ***On-site renewable energy generation:***

  Investment in on-site renewable energy generation as a means of supplying low-cost electricity is becoming increasingly attractive at WWTPs. Waste-to-energy and solar generation technologies are common options.

  Waste-to-energy scores highly on several factors including its reliability and scalability as long as there is enough land space and alternative waste feedstock available (e.g. municipal organic waste). Whilst electricity costs can be higher than large-scale wind or solar generation, the ability to supply consistent electricity at a high average output can reduce overall hydrogen project costs and decreases supply shortage risks. This makes waste-to-energy an attractive option for businesses already accustomed to dealing with waste such as water utilities.

  Solar generation technologies are also worth considering given their potential to supply very low-cost electricity. However, their intermittency and lower average generation output mean that they may not be suitable as a sole source of energy for hydrogen projects where larger and more consistent volumes are required.

- ***Power Purchase Agreements:***

  Where land space or other constraints limit the ability to develop on-site renewable generation, sourcing electricity entirely from the grid is an option if the emissions are offset via renewable Power Purchase Agreements (PPAs). PPA prices in Australia are becoming increasingly competitive due to the reduction in large-scale wind and solar generation costs. Setting a long-term arrangement, or multiple arrangements, at a fixed strike price could provide security against future market volatility.

- ***Electrolyser operational strategies:***

  Some electrolyser technologies can quickly increase or decrease production according to market volatility, enabling flexible operational strategies that reduce electricity costs. For example, one strategy would be to increase production when prices are negative and reduce production during expensive peak periods. There is also potential to create additional revenue by participating in ancillary services markets such as frequency control. These markets can provide revenue to participants who can quickly contribute to demand when there is an oversupply of generation, or vice versa. In simple terms, an electrolyser with a suitable control system can perform the same role as a battery in responding to market events.

# The impact of the market price for pure oxygen should be investigated

There is no transparent market price for pure oxygen and future work should consider how the price of oxygen produced by a hydrogen facility compares to the price of oxygen sourced from existing suppliers. If the market price for oxygen is lower than the minimum viable sale price for the hydrogen facility, the business case for transitioning to oxygen-based treatment is stronger, but the case for co-location is weaker.

The decision to continue with the hydrogen facility project and pay a premium price for oxygen would need to be justified to make sure it does not impose unnecessary costs on water utilities' customers.

## Depending on the premium, this decision should be weighed against the following factors:

***Relative emissions intensity:***

Oxygen available on the market is energy intensive and may not be emissions-free. Whilst 'indirect' emissions are not included in the water sector's targets or pledges, buying high emissions intensity oxygen is not aligned with the intent of these commitments. The inherent carbon intensity of traditional oxygen supply chains must be a consideration when evaluating the environmental benefits of sourcing oxygen for wastewater treatment.

***Security of supply:***

As an essential service provider, ensuring continuity of WWTP operations is vital. On-site production of oxygen could reduce the risk of supply shortages or interruptions.

***Wellbeing benefits to consumers:***

It is worth investigating the value customers could place on using hydrogen to reduce local air and noise pollution, and whether they would be willing to pay a premium in order to deliver better liveability outcomes for their communities.

Where the market price of oxygen is cheaper than the minimum viable price of oxygen from the co-located hydrogen facility, a lower price could be accepted if there is a net increase in shared benefits across water utilities' portfolio of unregulated businesses. For example, Yarra Valley Water's (YVW) ReWaste plant faces a network constraint that limits its ability to sell excess energy to the grid. A guaranteed demand for additional renewable energy from the hydrogen facility may generate opportunities to increase revenue for ReWaste. Given that YVW is the owner of both businesses, a lower oxygen price might be appropriate if the increased revenue at ReWaste more than offsets any revenue lost from the hydrogen facility.

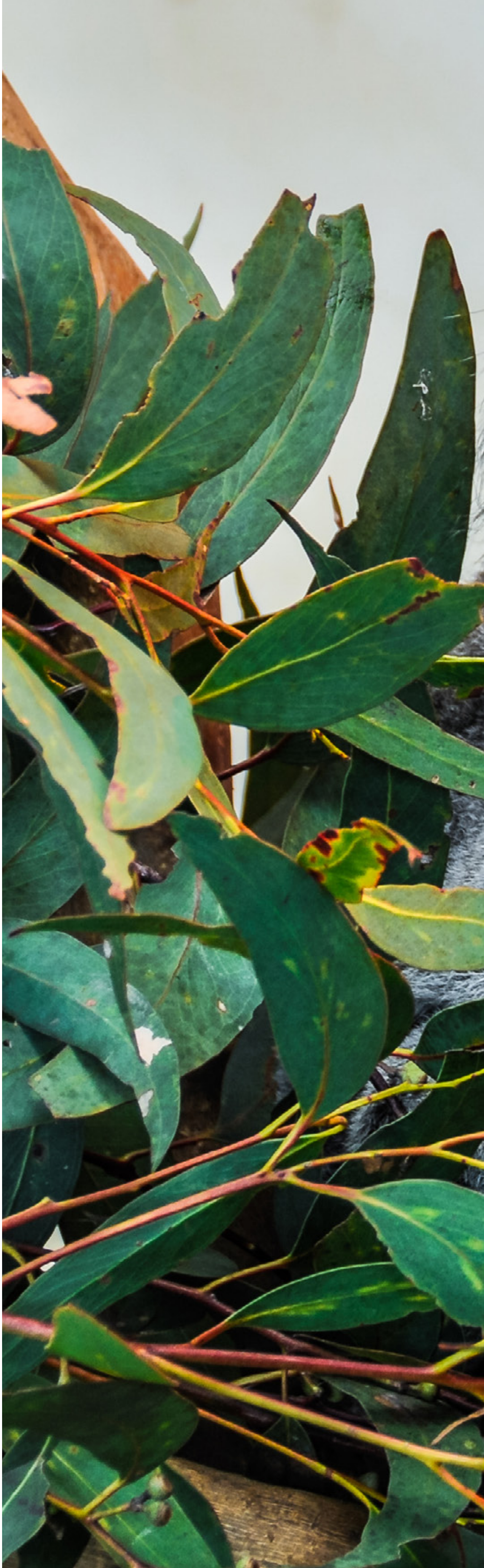
## Partnerships could lower risk to water utilities while still accelerating the market

If water utilities are not interested in owning and operating a hydrogen facility, it may be worth exploring partnership opportunities with other private operators. This includes industrial gas suppliers, some of whom have already demonstrated interest in sustainable hydrogen.[17] Partnerships with private operators would allow existing expertise and project learnings to be leveraged. Partnership arrangements could also extend to energy providers who own generation assets with access to competitive renewable electricity price contracts.



## Supporting hydrogen demand security through novel business models

While not a focus of the paper, assessing the business model for the hydrogen produced is an important step in supporting WWTP-based hydrogen hub development. For example, it is worth exploring how security of demand for hydrogen could be supported through the use of novel contract arrangements which adopt innovative risk-sharing methods. This could include offering contracts to hydrogen buyers where the base price of hydrogen is matched against the price of the alternative product. For example, hydrogen could be partially linked to diesel prices for contracts with transport users. This would improve financial security for hydrogen buyers whilst stimulating demand for the hydrogen producer.



CHAPTER SIX

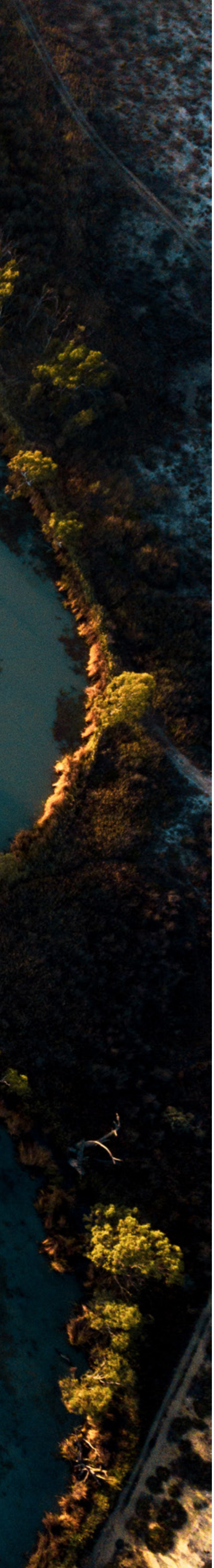
# Conclusion

Our paper assessed whether the commercial viability of sustainable hydrogen could be improved by co-locating production at wastewater treatment plants (WWTPs). The findings from our case study indicated that implementing oxygen-based MABR treatment at the Aurora WWTP could deliver net savings to Yarra Valley Water. The guaranteed demand for oxygen from the WWTP was instrumental in enabling the co-located hydrogen facility to be commercially viable while selling sustainable hydrogen at a competitive price. Although the results are specific to the unique circumstances of the Aurora WWTP, they suggest that water utilities may have a pivotal role to play in accelerating the development of Australia's hydrogen industry.

Co-locating sustainable hydrogen production with some types of oxygen-based treatment at WWTPs could bring wider economic and social benefits and could improve the prospects of developing hydrogen hubs. This could be an important step to fully developing a hydrogen industry and enabling more rapid decarbonisation of the nation's most emissions-intensive industries.

Based on the case study results, it is recommended that whenever a WWTP is due for replacement, renewal, or refurbishment, the benefits of transitioning to oxygen-based treatments should be considered alongside an assessment of whether an on-site hydrogen facility would be commercially viable. A critical next step in applying these findings will be to conduct detailed feasibility studies on the technical and commercial viability of co-locating hydrogen facilities at a range of WWTPs in Australia.

On a broader level, the analysis presented in this paper is an example of the benefits of taking an inter-disciplinary approach to tackling the world's toughest challenges. Moving forward, decisions related to hydrogen will require expertise from across a broad range of disciplines to effectively account for the full range of opportunities. The interconnectedness of water and energy in realising the potential of a hydrogen industry is just one example of how taking a broader view can generate mutually beneficial outcomes for businesses from diverse sectors and ultimately increase the liveability of our communities.



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# APPENDICES

## Appendix A: Results for all sensitivities tested

**TABLE 5**

*Scenario 1 (OCAT) sensitivity test results*

| Test # | Variable tested | Base assumption | Test | Maximum NPV at hydrogen facility |
|---|---|---|---|---|
| Base results | NA | NA | NA | -$38.07 m |
| 1 | Discount rate: | 5% | 3% | -$51.19 m |
| 2 | Discount rate | 5% | 7% | -$29.21 m |
| 3 | % of hydrogen sold | 50% | 25% | -$46.37 m |
| 4 | % of hydrogen sold | 50% | 100% | -$21.48 m |
| 5 | Energy price | 100% | 70% | -$23.62 m |
| 6 | Energy price | 100% | 150% | -$62.16 m |
| 7 | Efficiency improvement of using pure oxygen with OCAT | 15% | 10% | -$38.23 m |
| 8 | Efficiency improvement of using pure oxygen in current plant | 15% | 30% | -$37.56 m |
| 9 | Capex savings using pure oxygen with OCAT | 15% | 10% | -$43.31 m |
| 10 | Capex savings using pure oxygen with OCAT | 15% | 30% | -$22.36 m |
| 11 | Opex costs (as % of capex) | 3% | 2% | -$36.25 m |
| 12 | Opex costs (as % of capex) | 3% | 5% | -$41.72 m |
| 13 | Hydrogen Market Price | $4 | $2 | -$46.37 m |
| 14 | Hydrogen Market Price | $4 | $6 | -$29.78 m |
| 15 | % of ACCU revenue included | 0% | 50% | -$37.36 m |
| 16 | % of ACCU revenue included | 0% | 100% | -$36.64 m |
| 17 | Hydrogen plant capex | 100% | 50% | -$29.88 m |
| 18 | Hydrogen plant capex | 100% | 150% | -$46.26 m |

* This is a maximum and would be shared between the hydrogen facility and the Aurora WWTP.

**TABLE 6**

*Scenario 2 (OMT) sensitivity test results*

| Test # | Variable tested | Base assumption | Test | Maximum NPV at hydrogen facility |
|---|---|---|---|---|
| Base results | NA | NA | NA | $6.07 m |
| 1 | Discount rate: | 5% | 3% | $5.37 m |
| 2 | Discount rate | 5% | 7% | $6.04 m |
| 3 | % of hydrogen sold | 50% | 25% | $1.92 m |
| 4 | % of hydrogen sold | 50% | 100% | $14.37 m |
| 5 | Energy price | 100% | 70% | $12.80 m |
| 6 | Energy price | 100% | 150% | -$5.14 m |
| 7 | Efficiency improvement of using pure oxygen with OMT | 40% | 20% | $5.49 m |
| 8 | Efficiency improvement of using pure oxygen in current plant | 40% | 60% | $6.66 m |
| 9 | Capex savings using pure oxygen with OMT | 30% | 20% | -$4.40 m |
| 10 | Capex savings using pure oxygen with OMT | 30% | 40% | $16.55 m |
| 11 | Opex costs (as % of capex) | 3% | 2% | $7.02 m |
| 12 | Opex costs (as % of capex) | 3% | 5% | $4.17 m |
| 13 | Hydrogen Market Price | $4 | $2 | $1.92 m |
| 14 | Hydrogen Market Price | $4 | $6 | $10.22 m |
| 15 | % of ACCU revenue included | 0% | 50% | $6.43 m |
| 16 | % of ACCU revenue included | 0% | 100% | $6.79 m |
| 17 | Hydrogen plant capex | 100% | 50% | $10.17 m |
| 18 | Hydrogen plant capex | 100% | 150% | $1.98 m |
| 19 | MABR membrane asset life | 20 years | 10 years | $3.78 m |

* This is a maximum and would be shared between the hydrogen facility and the Aurora WWTP.

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Published June 2020.