Singapore International Water Week April 2022:

Hydrogen Circular Economy: Viability, Scalability, & Risk For Water Industry

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Introduction

Integration of sustainable hydrogen (H_2) production with capture of associated greenhouse gases & carbon, & local use of co-products:

- facilitate an emerging circular economy,
- help the water industry to achieve net zero carbon emissions,
- supply chain security for water treatment chemicals.

In particular, green hydrogen & co-products such as O_2, O_3 and H_2O_2 are essential within an emerging circular economy:

- sustainable fuels,
- chemical synthesis feedstocks,
- oxidising agents for AOP.

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Introduction

Wastewater treatment plants produce large quantities of recycled water & biogas, providing co-location opportunities for hydrogen production and alternative reuse prospects:

- Water source concerns for sustainable hydrogen,
- Reinforces circular economy principles of wastewater as a valuable resource,
- Avoids potentially harmful wastewater discharges to the environment,
- Reduces capital expenses by using existing infrastructure, land, & supply chains.
- + recycled-water-based drought schemes may have potential for hydrogen production during non-drought periods.

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Challenge

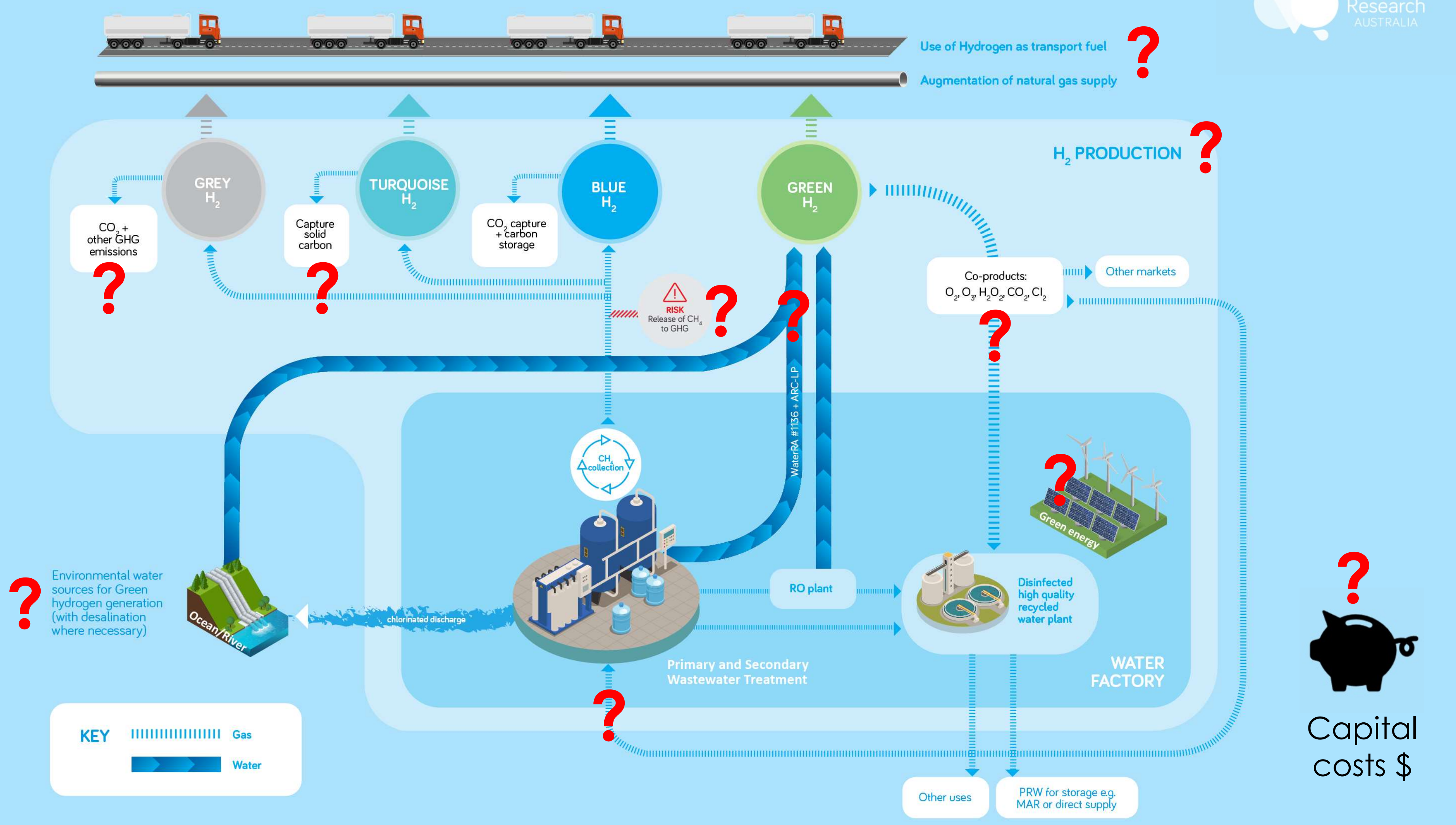
While hydrogen production opportunities may add significant value to WWTP operations:

- Associated risks
- Viability?
- Scalability?
- Urban and regional perspectives?
- Value proposition of a hydrogen circular economy to water industry stakeholders?

Objective

- Understand these concerns and provide site-specific guidance to prospective utilities aiming to address technical considerations of feasibility, scalability and viability
- Formulate a decision tree to support utility decision-making and risk assessment.

Conceptual model of how the water industry can drive a circular economy



Economic viability

Understand the economic viability of hydrogen production:

- Projected future demands for hydrogen & associated supply chain
  - The global hydrogen industry is expected to increase 40% by 2030, with Australia aiming to become a leading exporter of hydrogen, with potential export values of $5.7bn by 2040.
  - To accelerate the development of a hydrogen economy and transition to a decarbonised future, we need to produce “clean” hydrogen at under AU$2.00 per kilogram.



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Economic viability

Understand the economic viability of hydrogen co-products:

- Projected future demands for co-products: O_3
  - The global O_3 market size was valued at USD $ 880 million in 2016 and is expected to grow at a compound annual growth rate (CAGR) of 7.4% from 2017 to 2023.
  - O_3 generators predominantly use air as the feed, but when oxygen is used, more ozone can be generated at lower energy consumption.
- Projected future demands for co-products: H_2O_2
  - Use in water industry; food, paper and pulp; chemical manufacturing; pharmaceutical & health; disinfectant products.
  - The global hydrogen peroxide market size was valued at USD 1.44 billion in 2020 and is expected to grow at a compound annual growth rate (CAGR) of 5.7% from 2020 to 2028.
    - *Can production of co-products offset the production cost of H_2, bringing the cost of H_2 production down to the targeted $2/kg?*

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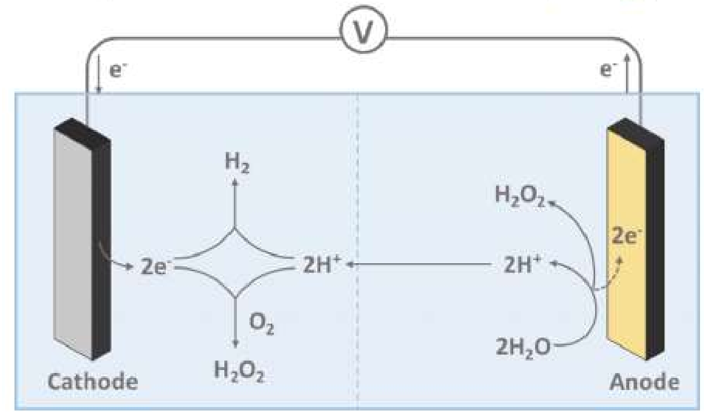
Technical viability

The technical viability of recycled-water-based hydrogen production also presents many research questions:

- Performance of electrolysers (which split water into hydrogen and oxygen in the presence of a catalyst)
  - low pH conditions ideal for hydrogen reduction
- Volumes of (recycled) water required
- Optimal operating conditions
- Impacts of contaminants in wastewater:
  - organic compounds
  - metal ions
  - nutrients
  - inorganic debris

Principles of electrochemical water splitting



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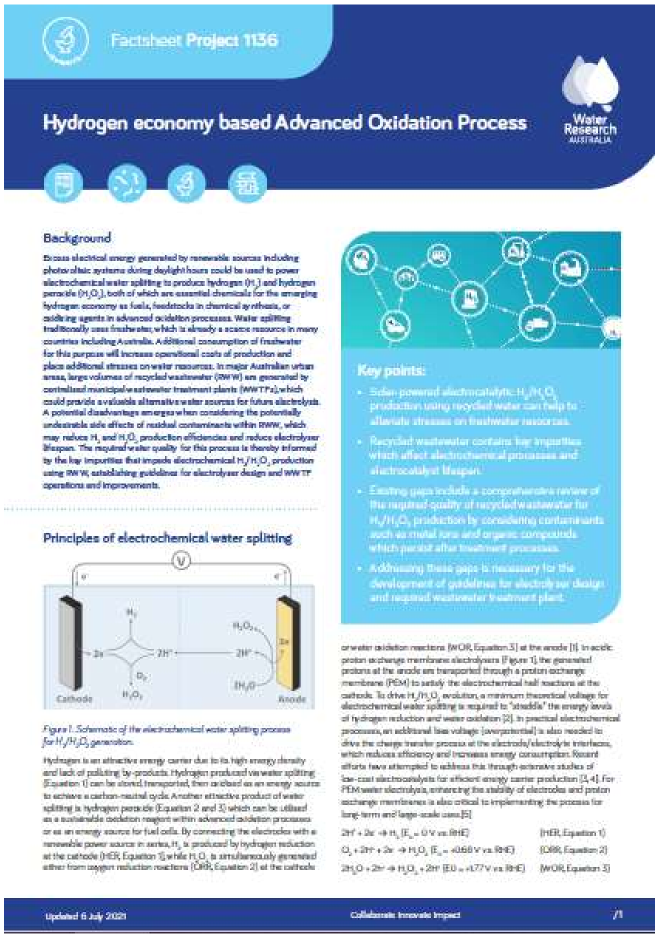
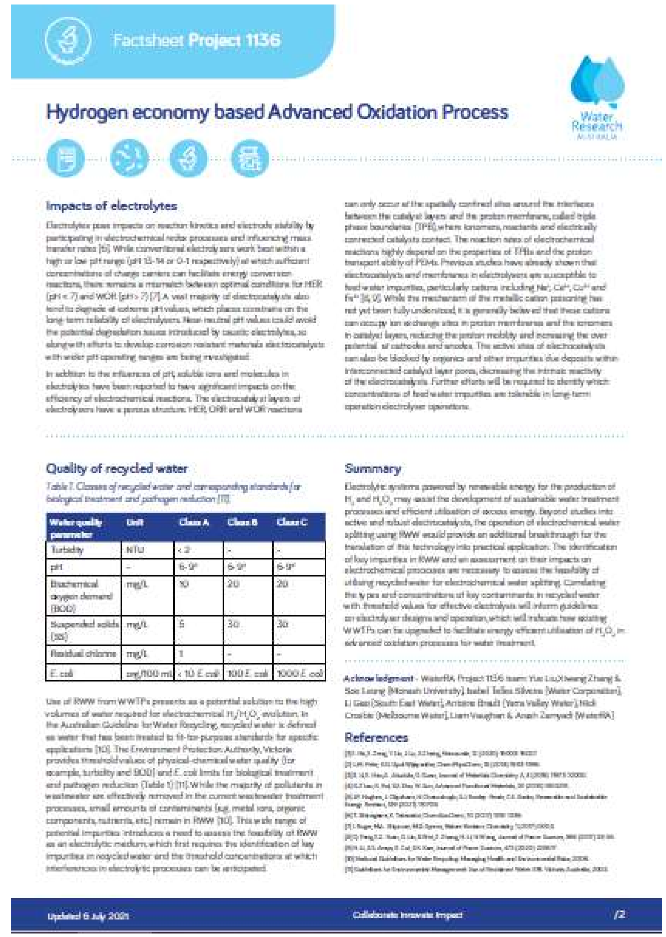
Technical viability: WaterRA factsheet

https://www.waterra.com.au/_r11390/media/system/attrib/file/2690/WaterRA_FS_1136_HydrogenEconomy.pdf





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Technical viability

3-year ARC linkage project: Sustainable Hydrogen Production from Used Water

Objectives

1. To gain an in-depth understanding of how existing electrolysers perform in the presence of water impurities, and develop guidelines for designing water electrolysers with high tolerance of water
2. To identify the water quality gap between the treated water from existing WWTPs and the required feed water for water electrolysis, and provide recommendations for WWTPs operation and potential upgrading;
3. To evaluate the technical feasibility of utilising the co-products from waster electrolysis in wastewater treatment, and develop frameworks for the integration between wastewater treatment and water electrolysis.

Project partners & funding model

Water Research Australia

WaterRA water industry consortium:

Yarra Valley Water

South East Water

Water Corporation

Melbourne Water

Barwon Water

Energy sector: Leverage 1$:6$

GRAPHENEX

Academic research:

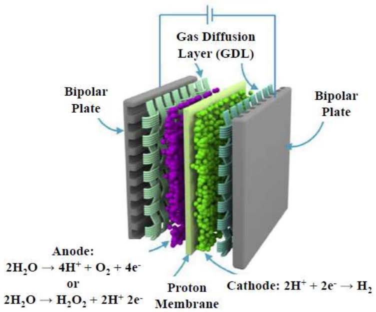
The University of Queensland Australia

Monash University

Academic research: Leverage 1$:11$

Australian Government

Australian Research Council



Technical viability: ***Impacts of impurities*** *& mitigation strategies*

	TYPES	MECHANISMS	PERFORMANCE
Failure of exchange membranes	• Mechanical damage, e.g. cracks, pores • Membrane degradation • Active site occupation	• O_2 permeation • Low conductivity	Activity decay
Electrode catalyst damage	• Dissolution/corrosion of catalysts • Poisoned by impurities • Agglomeration of catalysts • Passivation of catalysts/supports	• Changes in chemical/ structural features	

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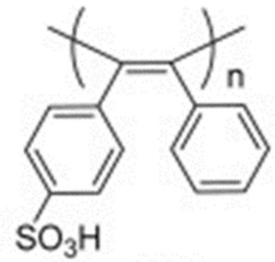
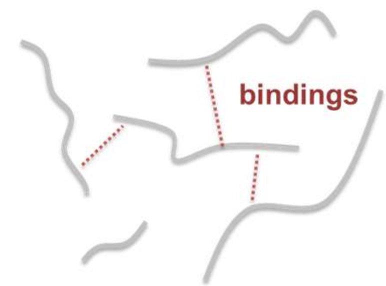
Technical viability: ***Impacts of impurities** & mitigation strategies*

Exchange membranes

- Developing tough polymer
- Engineering methods (e.g. refreshing the electrolyte)
- Hybridization with binder ionomers

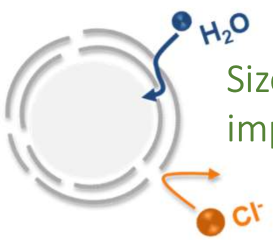
Hydrocarbon polymer





Perfluorosulfonic acid ionomers

Electrode catalysts

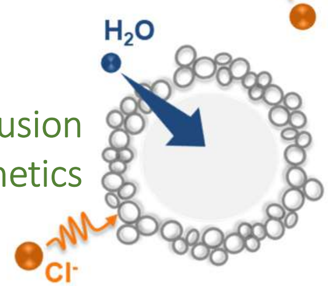


Size exclusion of impurities

Repelling of impurities

Full wrapping

Slower diffusion kinetics



- Developing active & robust catalysts
- Post-treatment (e.g., acidic washing)
- Introducing protective shells

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Technical viability

- Volumes of water required: Theoretically 9kg of H_2O to produce 1 kg H_2. At scale: estimated to be up to 90 kg electrolyser cooling
- Energy consumed for hydrogen production

Manufacturer	Technology Name	Operating Pressure	Hydrogen Flowrate	Energy Consumption	Operating Range	Water Consumption	Power	Electrical Efficiency
Manufacturer 1	HOGEN S10	13.8 bar_g	0.265 Nm^3/hr - 0.57kg/d	74 kWh/kg H_2	0-100%	9.9 L/kg H_2	1.1 kW	-
	HOGEN S20		0.53 Nm^3/hr - 1.14 kg/d				2.2 kW	-
	HOGEN S40		1.05 Nm^3/hr - 2.27 kg/d				4.3 kW	-
	H2	15 bar_g / 30 bar_g option	2 Nm^3/hr	81 kWh/kg H_2	0-100%	10.2 L/kg H_2	8.1 kW	-
	H4		4 Nm^3/hr	78 kWh/kg H_2			16.1 kW	-
	H6		6 Nm^3/hr	76 kWh/kg H_2			23.7 kW	-
Manufacturer 2	ME 100/350	15 - 30 bar_g	15-46.3 Nm^3/hr	55 kWh/kg H_2	32-100%	14.4 L/kg H_2	225 kW	73%
	ME 450/1400	15 - 30 bar_g	42-210 Nm^3/hr	53 kWh/kg H_2	20-100%	13.8 L/kg H_2	1 MW	74%
	HCS 2MW	15 - 30 bar_g	420 Nm^3/hr	<53 kWh/kg H_2	20-100%	16 L/kg H_2	2 MW	>74%
	HCS 4MW	15 - 30 bar_g	840 Nm^3/hr			17 L/kg H_2	4MW	
	HCS 10MW	15 - 30 bar_g	2100 Nm^3/hr			18 L/kg H_2	10MW	
	S30/10	0 - 20 bar_g	0.22 Nm^3/hr	-	-	29 kg/hr	1 kW	78%
	S30/30	0 - 20 bar_g	0.66 Nm^3/hr	-	-	87 kg/hr	3 kW	
	S30/50	0 - 20 bar_g	1.10 Nm^3/hr	-	-	145 kg/hr	5 kW	
Manufacturer 3	HyLYZER 200	30 bar_g	200 Nm^3/hr	<55 kWh/kg H_2	5 - 100%	9 L/kg H_2	-	-
	HyLYZER 250		250 Nm^3/hr					
	HyLYZER 400		400 Nm^3/hr	<54 kWh/kg H_2				
	HyLYZER 500		500 Nm^3/hr					
	HyLYZER 1000		1000 Nm^3/hr	<51 kWh/kg H_2	5 - 125%			
Manufacturer 4	SILYZER 200	35 bar	225 Nm^3/h	-	-	17 L/kg H_2	1.25 MW	60-65%
	SILYZER 300	-	1300 kg/hr	-	0-100%	10 L/kg H_2	~70 MW	>75.5 %

Scalability of production processes

- The scalability of production processes is also a key concern:
  - Regional utilities: many plants distributed across a large geographic area.
- The risks associated with utility involvement in a hydrogen circular economy are also poorly defined:
  - Core business of a water utility?
- From a sustainability perspective a key potential risk is the allocation of water for hydrogen production in regions where water resource availability is subject to extreme variability due to climate change.
  - In this context, how can we not only secure water for electrolysis but continue to meet accessibility and affordability for other uses?

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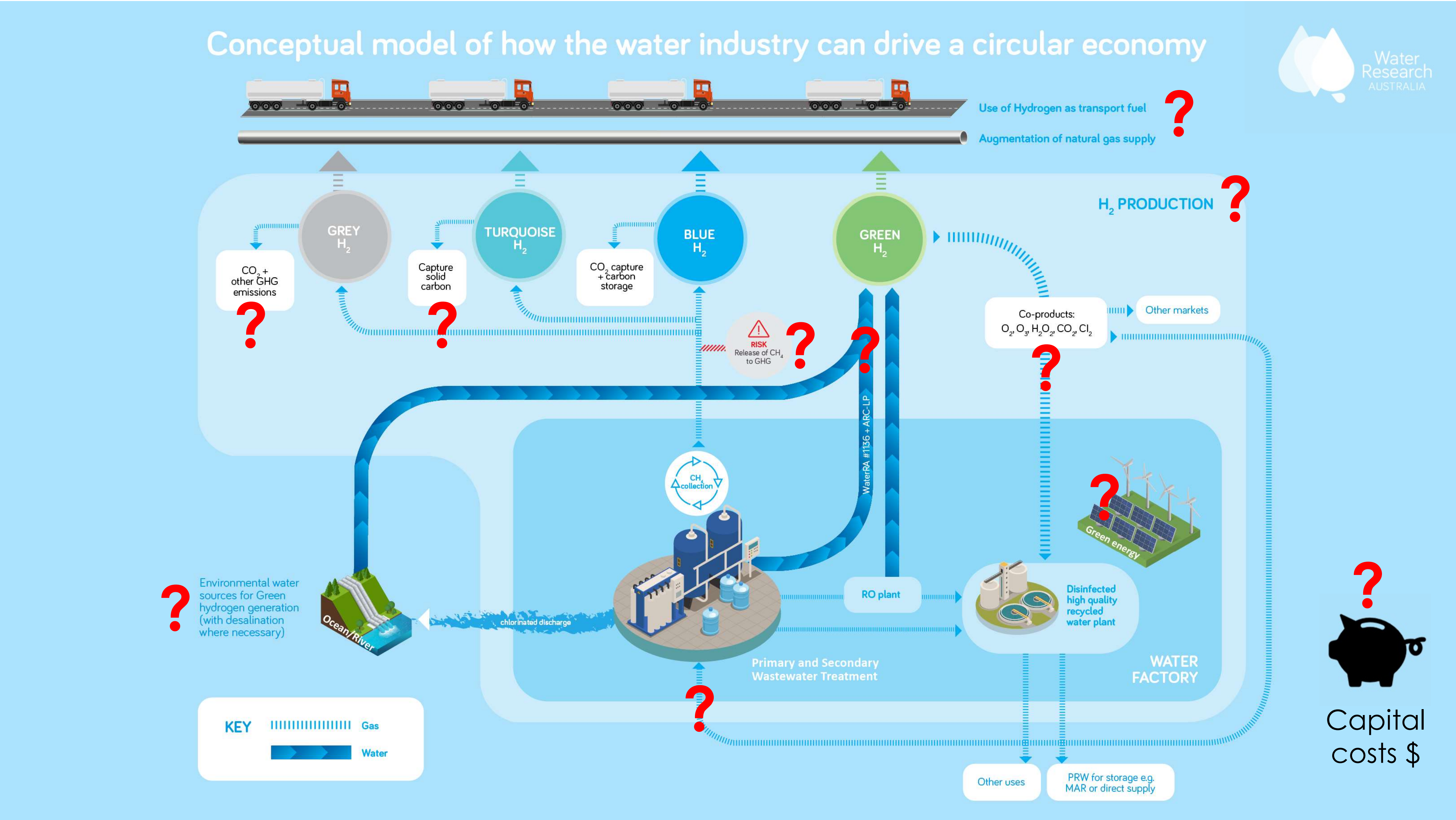

Conceptual model of how the water industry can drive a circular economy
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Use of Hydrogen as transport fuel
Augmentation of natural gas supply
H2 PRODUCTION
GREY H2
TURQUOISE H2
BLUE H2
GREEN H2
CO2 + other GHG emissions
Capture solid carbon
CO2 capture + carbon storage
RISK Release of CH4 to GHG
Co-products: O2, O3, H2O2, CO2, Cl2
Other markets
WaterRA #1136 + ARC-LP
CH4 collection
Green energy
Environmental water sources for Green hydrogen generation (with desalination where necessary)
Ocean/River
chlorinated discharge
Primary and Secondary Wastewater Treatment
RO plant
Disinfected high quality recycled water plant
WATER FACTORY
KEY
Gas
Water
Other uses
PRW for storage e.g. MAR or direct supply
Capital costs $

Scalability:

WaterRA water industry consortium

Water “core partnership” workshop May 6th 2022 (online) - Themes:

- Water sources and their social licence;
- Technology needs for water reuse and beneficial co-products;
- Co-location opportunities (including renewable energy generation) and Integrated planning.

Contact me to join the workshop:
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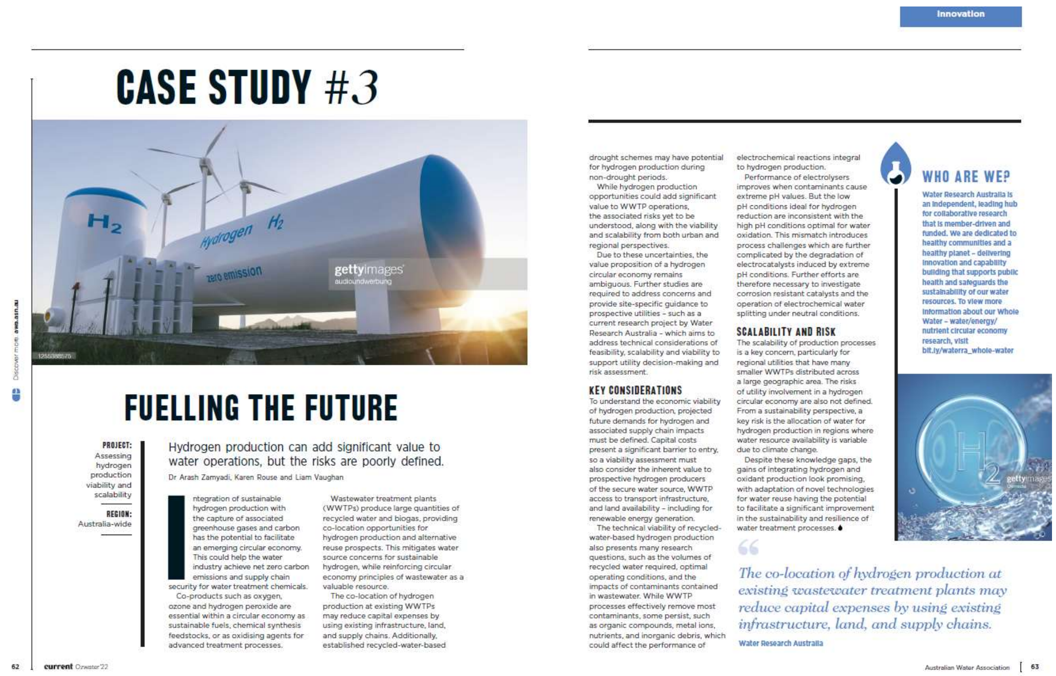
Conclusion

- For successful integration of hydrogen and oxidant production into existing and newly developed water/wastewater treatment facilities, research questions regarding viability, scalability, sustainability and risks must be addressed.

- The potential gains are however promising, and adaptation of novel technologies for water reuse could facilitate a significant improvement in the sustainability and resilience of water treatment processes.



Innovation

CASE STUDY #3

FUELLING THE FUTURE

PROJECT: Assessing hydrogen production viability and scalability

REGION: Australia-wide

Hydrogen production can add significant value to water operations, but the risks are poorly defined.

Dr Arash Zamyadi, Karen Rouse and Liam Vaughan

Integration of sustainable hydrogen production with the capture of associated greenhouse gases and carbon has the potential to facilitate an emerging circular economy. This could help the water industry achieve net zero carbon emissions and supply chain security for water treatment chemicals.

Co-products such as oxygen, ozone and hydrogen peroxide are essential within a circular economy as sustainable fuels, chemical synthesis feedstocks, or as oxidising agents for advanced treatment processes.

Wastewater treatment plants (WWTPs) produce large quantities of recycled water and biogas, providing co-location opportunities for hydrogen production and alternative reuse prospects. This mitigates water source concerns for sustainable hydrogen, while reinforcing circular economy principles of wastewater as a valuable resource.

The co-location of hydrogen production at existing WWTPs may reduce capital expenses by using existing infrastructure, land, and supply chains. Additionally, established recycled-water-based drought schemes may have potential for hydrogen production during non-drought periods.

While hydrogen production opportunities could add significant value to WWTP operations, the associated risks yet to be understood, along with the viability and scalability from both urban and regional perspectives.

Due to these uncertainties, the value proposition of a hydrogen circular economy remains ambiguous. Further studies are required to address concerns and provide site-specific guidance to prospective utilities – such as a current research project by Water Research Australia – which aims to address technical considerations of feasibility, scalability and viability to support utility decision-making and risk assessment.

KEY CONSIDERATIONS

To understand the economic viability of hydrogen production, projected future demands for hydrogen and associated supply chain impacts must be defined. Capital costs present a significant barrier to entry, so a viability assessment must also consider the inherent value to prospective hydrogen producers of the secure water source, WWTP access to transport infrastructure, and land availability – including for renewable energy generation.

The technical viability of recycled-water-based hydrogen production also presents many research questions, such as the volumes of recycled water required, optimal operating conditions, and the impacts of contaminants contained in wastewater. While WWTP processes effectively remove most contaminants, some persist, such as organic compounds, metal ions, nutrients, and inorganic debris, which could affect the performance of electrochemical reactions integral to hydrogen production.

Performance of electrolysers improves when contaminants cause extreme pH values. But the low pH conditions ideal for hydrogen reduction are inconsistent with the high pH conditions optimal for water oxidation. This mismatch introduces process challenges which are further complicated by the degradation of electrocatalysts induced by extreme pH conditions. Further efforts are therefore necessary to investigate corrosion resistant catalysts and the operation of electrochemical water splitting under neutral conditions.

SCALABILITY AND RISK

The scalability of production processes is a key concern, particularly for regional utilities that have many smaller WWTPs distributed across a large geographic area. The risks of utility involvement in a hydrogen circular economy are also not defined. From a sustainability perspective, a key risk is the allocation of water for hydrogen production in regions where water resource availability is variable due to climate change.

Despite these knowledge gaps, the gains of integrating hydrogen and oxidant production look promising, with adaptation of novel technologies for water reuse having the potential to facilitate a significant improvement in the sustainability and resilience of water treatment processes.

The co-location of hydrogen production at existing wastewater treatment plants may reduce capital expenses by using existing infrastructure, land, and supply chains.

Water Research Australia

WHO ARE WE?

Water Research Australia is an independent, leading hub for collaborative research that is member-driven and funded. We are dedicated to healthy communities and a healthy planet – delivering innovation and capability building that supports public health and safeguards the sustainability of our water resources. To view more information about our Whole Water – water/energy/ nutrient circular economy research, visit bit.ly/waterra_whole-water

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Thank you

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