INTRODUCING HYDROGEN FOR ENERGY AS A NEW WATER USER

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ABSTRACT

Australia is positioning itself to become a hydrogen generation powerhouse and could bring hydrogen online as a net exporter of resources globally. Additionally, the transition towards renewable energy and a more sustainable future has led to the emergence of ‘green’ hydrogen (where hydrogen production via electrolysis is powered by renewable energy).

Water quality and availability is a key factor for green hydrogen production and has its own challenges. Tasmania is perceived as having an abundance of high-quality water for hydrogen production. However, proximity to available water is a key issue and the ideal hydrogen production locations, from an end user perspective, will not always co-locate with abundant, high-quality water. Available water sources include sea, surface, mine, industrial, domestic wastewater, and groundwater. Yet practically, the nearest available water source is often used in hydrogen production, which may result in varying levels of treatment requirements and cost implications depending on the water quality.

This context introduces hydrogen production as a disruptive factor to the urban water cycle and the water cycle more generally. Hydrogen production facilities are users of water in multiple ways; in the electrolysis and cooling processes, as an energy user (hydro power for green hydrogen) and as a producer of high-quality water). As a consequence, hydrogen production can have a positive or negative impact on urban or irrigation water security.

Water for hydrogen is demineralised and typically has an Electrical Conductivity (EC) <0.5 µS/cm, which due to source water availability, requires many treatment steps (e.g., two-pass RO, electrodeionisation, etc). This leads to more than the stoichiometric demand of 9 L/kg H_2 required to be sourced.

Cooling water is also required unless air cooling is possible, however it does not require the same high-water quality as the electrolyser. Cooling water can require some treatment, e.g., for health issues such as legionella and depending on the number of cycles of concentration, can become a large volume. In addition, brine management is crucial, particularly if ocean disposal is not possible due to location, such as inland Reverse Osmosis (RO). For brackish applications, thermal treatment or concentration of brine may be required.

This paper will investigate several scenarios for how green hydrogen can be produced within Tasmania, and associated impacts to the urban and natural water cycle. In addition, potential opportunities and lessons learnt from real-world case studies will be shared to help decrease water requirements, with improved water qualities and beneficial reuse opportunities identified to help justify investment of capital in future.

INTRODUCTION

Hydrogen is an energy carrier which can be used in future energy to transition away from fossil fuels through the use of renewable energy. Large future demands have been projected through this transition, which will align with numerous United Nations Sustainable Development Goals (UNSDGs). Depending on the production method, hydrogen is assigned a colour label. For example, “green” hydrogen is made using renewable energy, and “blue” hydrogen is made using Steam Methane Reforming (SMR) and includes carbon capture and storage (CCS) to lower the carbon footprint. It is important however to reinforce that whilst colours are assigned to hydrogen based on the production method, it is still the same element produced and is rarely found as “white” hydrogen in its natural occurring (unbonded) form. There are many production methods assigned to this separation of hydrogen from various forms in which it can be sourced. Figure 1 outlines this “hydrogen rainbow” showing the various colours and their associated production method.

Current estimates indicate that the 2050 world hydrogen demand could reach 580 Mt per year with over 60% of this from renewable green hydrogen (IRENA, 2021). Of this world demand, it is expected that Australia could produce 1 Mt per year for export by 2030 (ACIL Consulting for ARENA, 2018) and 45 Mt per year by 2050, making it a $90 billion industry (Murray, 2021). In conjunction with the production hydrogen gas for export, there will be domestic uses including integration with gas networks, hydrogen fuel cells for transportation and energy storage for remote communities, which could add an additional 230 Mt per year (Pendlebury, Meares, & Tyrrell, 2021).

Tasmania has high renewable energy contribution through hydropower and wind, abundant fresh water and industrial precincts with land and infrastructure (Tasmanian Government, 2020). However, this application will require large volumes of water to meet this demand, which will need to be considered as Tasmania looks to integrate hydrogen for energy as a new water user.

Figure 2 presents the Tasmanian renewable hydrogen production and end use flowchart which outlines domestic end use applications including remote power stations, industrial applications, transport or blending with natural gas.

There are numerous source waters within Tasmania which can be used to feed a hydrogen gas plant. These include recycled water, seawater, wastewater, surface water and bore water which all have varying levels of treatment required to meet the feed requirements to the hydrogen production unit. Climate change modelling shows a complex change of runoff patterns throughout the state in the future (with a significant reduction in the central highlands and increases in eastern and other areas and differentiated seasonal impacts (Bennett, et al., 2010)). Therefore, there is a need for water planners and users, on behalf of communities, to consider the various aspects of the water related economy and what competitive or synergistic uses exist now and in the future. Significantly, some prediction models for irrigator water storages in the central highlands show significant inflow reduction in the year 2100 of up to 48% for some areas (Bennett, et al., 2010) with notable impacts by 2030 (CSIRO, 2009) The World Water Development Report 2020 clearly outlines the importance of water and climate change, the importance of the water-energy nexus, and calls on the community to “give greater attention to the role of water and recognize its central importance in addressing the climate change crisis” (UNESCO, 2020). One study finds that up to $312 billion, one third of Australia’s economy, could be lost due to the effect of floods, droughts and storms between 2022 and 2050 (GHD, 2022). This illustrates that it is key to determine the projected water requirements for the emerging green hydrogen industry and determining how this would factor into future planning.

One approach for how community values and water availability might be considered is through the application of systems thinking, adaptive planning and resilience principles.

Resilience and Adaptive Planning

Churchman discusses the complex relationship between organisations, values, communities and projects through a framework of systems thinking that gives rise to a pragmatism for complex solving of ‘wicked problems’ (Churchman, 1971). This ‘lens’ of considering the dynamic relationships between actors within the community can help expose the competitive and synergistic uses of water. This broad view and a ‘swooping in’ approach (Williams & Hof, 2016) rapidly shows that stakeholder values intersect and, through engagement, can give rise to ‘wicked solutions’ (that is, solutions to ‘wicked problems’).

This sets the stage for interagency and coopetitive collaboration (Bouncken, Gast, Kraus, & Bogers, 2015) between stakeholders at different levels as well as considering collaboration levels and styles of deliberative engagement between various stakeholder groups. Also, the role of government, industry and communities in decision making.

The goals of any such engagement with stakeholders will be regarding the opportunity to improve or safeguard resilience of the water system (for environmental, commercial/irrigator/industrial, or residential use). This resilience could be considered like engineering resilience (Woods, 2006) or from a community/sustainable livelihoods perspective (DFID, 1999), which may be more pertinent. In the case of green hydrogen in Tasmania, this focus of the collaboration activity is to create value to the community by exploring the water-energy nexus.

Stakeholder values and perspectives are complex and changing over time (Haasnoot, Kwakkel, Walker, & ter Maat, 2013) and so to achieve the goal of robust infrastructure planning while simultaneously aiming for a high level of certainty may result in inflexibility and costly retrofits to accommodate for uncertainties that arise from both changing stakeholders but also, in the case of green hydrogen, climate and economic factors (Siebentritt & Stafford-Smith, 2014).

This ever-changing decision context gives rise to the current approach and methodologies of Adaptive Pathways (Gorddard, Colloff, Wise, Ware, & Dunlop, 2016). Adaptive Pathways provide decision makers a simple way to show and test, in the face of uncertainty, how options can be implemented through time, and helps organisations to take the first steps (Bosomworth, Harwood, Leith, & Wallis, 2015).

Factors that make hydrogen gas production efficient based on location

The following factors are important, locationally dependant, inputs into the economic viability of a hydrogen gas facility;

- Access to customers
  - Export
  - Industrial/commercial
  - Domestic
- Access to energy
- Access to water
- Access to waste/brine disposal
- Access to workforce

METHODOLOGY

Selection of Case Studies

In order to provide a set of case studies for hydrogen production in Tasmania, different locations and technologies were reviewed. Locations were selected that had different natural values with regards to the hydrogen success factors listed above.

Water demands for Hydrogen production

The hydrogen production water demands were based on mass balances that were derived from each scenario's flow diagram (see Figure 3 for an example). These were undertaken according to the following steps:

1. The electrolyser size and efficiency were set and used to define the demineralised water requirements and cooling requirements.
2. The raw water quality and the recovery of the individual water treatment plant process units determined raw water requirements and the amount of waste stream produced.
3. The cooling plant type, number of cycles and cooling duty determined the make-up water requirements and the waste stream production.
4. The estimated quality of the various waste streams enabled estimation of whether they were able to be recycled into the water treatment process, whether water was recovered or disposed of.

Intersecting stakeholder values

A desktop exercise was carried out to create a foundation for understanding the basis of collaboration as a platform for adaptive pathways planning. The process used was informed by the Wicked Solutions book (Williams & Hof, 2016). It was;

1. With a wide view, identify the system or systems of relevance (see case studies below)
2. Identify stakeholders
3. Identify stakeholder perspectives and aspirations
4. Compare and contrast the stakeholder perspective and aspirations
5. Identify emergent themes of conflict or synergy

As a desktop exercise, developed by the authors of this paper, there are inherent limitations to this methodology, primarily;

- Limitation in awareness of stakeholders
- Limitation in understanding of stakeholder perspectives and aspirations

While true of all outcomes, the authors are keenly aware of a lack of understanding of on-the-ground stakeholders such as local communities, irrigators, traditional custodians and other “unknown unknowns” (Rumsfeld, 2002).

RESULTS/ OUTCOMES

Intersecting stakeholder values

Through the swooping in process, the following stakeholders were identified along with high level perspectives and aspirations (regarding how they view the emergence of green hydrogen production as a new water user in Tasmania and what their relevant want/needs might be - ie aspirations). This is shown in Table 1. The final two columns of Table 1 show how the stakeholder perspectives and aspirations interact with the goals of hydrogen production (this is an extract of the full stakeholder intersection exercise).

The documentation of the intersections, for example, finds that

- Competing for water; limited water resources to be allocated to most desirable use
- Competition for water; different water users working together to make new water sources more viable
- Inherent need for hydrogen to have an export linkage
- Synergies for the operation of water treatment infrastructure to assist in water security planning

Technical Challenges

Hydrogen production has many technical challenges to overcome, those particularly apparent to Tasmania include:

- Source water qualities. Depending on the source water used, the level of water treatment varies, including pre-treatment, Ultra Filtration (UF), single or two pass RO and demineralisation, as the electrolyser requires high feedwater quality.
- Energy supply. Green hydrogen requires the use of renewable energy to power its hydrogen production. As Tasmania produces a significant amount of renewable energy, Tasmania is also well placed to produce the renewable electricity for other regional to purchase for input into their own hydrogen production plants.
- Concentrate and temperature management. Brine management and potential warm water for cooling. The temperature of the waste water produced is usually higher than the intake. For

environmental reasons, it must not exceed temperature limits, which depend on location of disposal/return. Similar rules apply to the increased conductivity.
- Logistics; access to logistics for cost effective supply of hydrogen to customers is an important factor that constrains the potential locations of any hydrogen production facility. As a point of synergy, sea port locations also provide a close proximity for ocean disposal of reverse osmosis concentrate (brine)

Additionally, there are other challenges to overcome, such as:
- Economics. Is hydrogen economically viable when comparing the sale price to the costs of production, taking both capex and opex into account?
- Efficiencies. Electrolyser efficiency, stack efficiency etc still have a long way to go for green hydrogen production.
- Water demands. The significant amount of raw water that is required may result in water security challenges.
- Carriers. Hydrogen has a very low energy density, in order to be used, the energy density must be increased by either compressing, chemically combining, or liquefying, for safe storage and transportation.

Case Studies

Five case studies were developed, looking into producing hydrogen from various Tasmania locations, with differing types of cooling, and source water types. A summary of parameters used in these five scenarios can be found in Table 2. The five case study options consisted of:

- Industry / port based (Bell Bay Port), evaporative cooling
- Industry / port based (Bell Bay Port), evaporate direct seawater cooling
- Industry / port based (Bell Bay Port), once through cooling
- Irrigator / inland based (Midlands Irrigation Scheme), evaporative cooling
- Generator / dam based (King-Yolande), once through cooling

Using the parameters detailed in Table 2, Tables 3 (daily water capacity values) and 4 (water/hydrogen unit rate values) were produced. Table 3 summarises the capacities of each stage of hydrogen production for all options. Table 4 summarises the overall water demand for each option considered in terms of hydrogen produced, as well as the water demand for each stage of the production process. This showed that the option with the highest overall raw water demand was Option 3, requiring 1964 L/kg H_2. This option was for a coastal based hydrogen plant, at Bell Bay Port, using seawater as its feed, once through cooling, and disposing the waste to an ocean outfall. The option with the lowest raw water demand was Option 4, requiring 46 L/kg H_2. This option was the Midlands Irrigation scheme using surface water as its feed, and additionally implemented a blowdown water recovery plant and a brine treatment plant, disposing the brine waste to landfill.

Option 5 differs from the other case studies in terms of brine disposal, as it utilises dilution as a solution to brine management. The conductivity of the brine only increased slightly from 500 µS/cm to 500.26 µS/cm, a 0.05% rise in conductivity, therefore this is not an issue. However, there is a water temperature rise of 0.88 °C, which may prove to be an issue, particularly for an inland location when returning the waste water.

CONCLUSION

- There is a clear basis for collaboration between water extractors, treatment plant operations and users at different scales including;
  - Collaboration for RO operations
  - Coordination of water extraction licences / irrigation schemes
  - Competition between uses
- The water demand for hydrogen has the potential to result in hydrogen production being a significant user of water in the Tasmanian context, from 6 ML/d to 270 ML/d, per 300 MW of electrolyser capacity
- The challenge is to make use of the opportunity for collaboration to improve the resilience of Tasmanian communities as water uncertainty increases in the context of a variable and changing climate.

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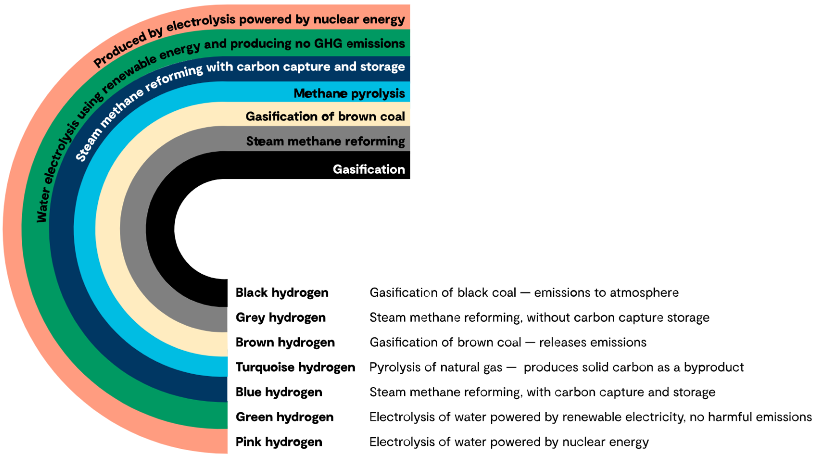

Figure 1 Hydrogen classified by colour based on the production pathway used (Potts & Coertzen, 2022)

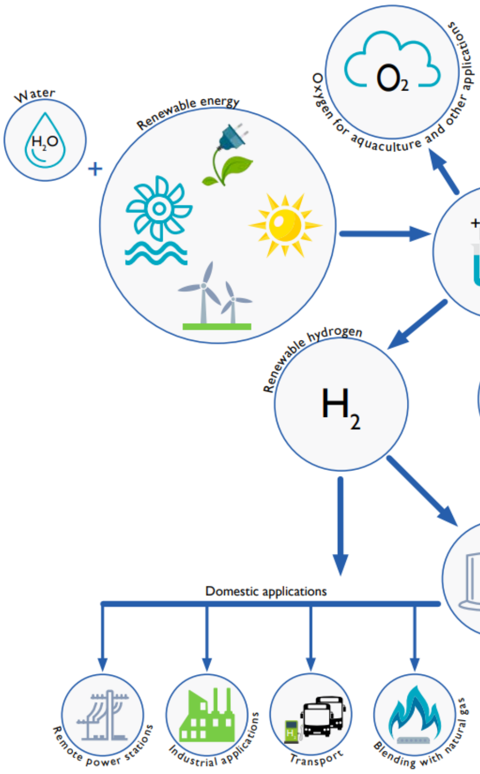

Figure 2 Tasmania hydrogen production and end uses (Tasmanian Government, 2020)

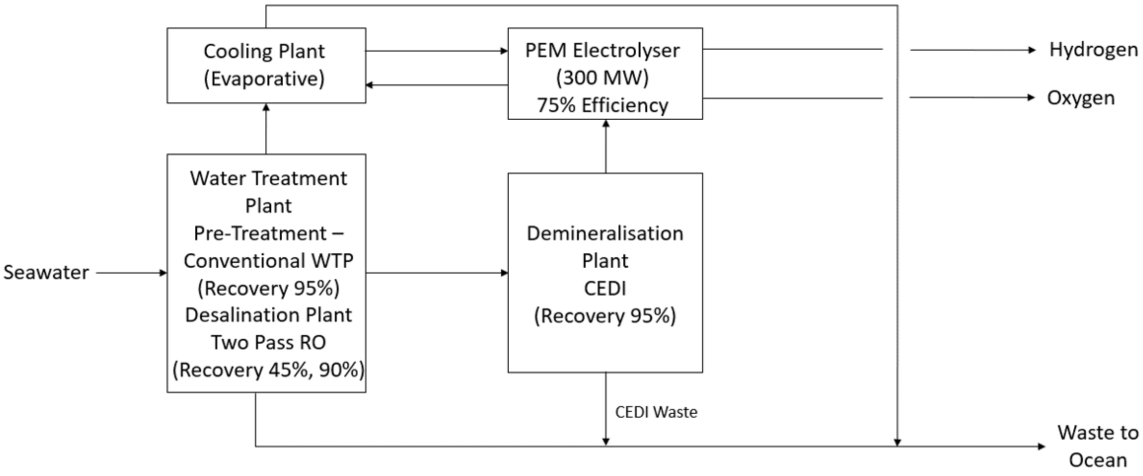

Figure 3 Example high-level process flow diagram used in case studies (Option 1)

Table 1 Stakeholder values intersection

Stakeholder	Perspective	Aspirations	How does this stakeholder intersect H_2 values	How does H_2 producer intersect stakeholder values
Hydrogen gas producer	Water security, quality, low cost	Multiple locations close to customer point of use (domestic/export)		
Local communities	Environmental values, economic opportunities	Improve catchment health while creating / protecting economic value	Expectations around brine management	Economic growth
Residential water customers	Water security, quality, low cost	Long term reliability of supply at lowest best cost	Workforce, domestic demand	Alternative water supply, additional potable water supply
Water Utility	Water security, quality, revenue, customer services	Resilience	Competition for water resources, can operate treatment infrastructure	New customer – revenue, addition secure water supply (in the case of RO)
Irrigation Utility	Water security, quality, revenue, customer services	Resilience	Competition for water resources, building new schemes	New users, new alternative water suppliers
Irrigators	Water security, quality, low cost	Long term reliability of supply at lowest best cost	Potential locations for facilities	Competition for water resources, collaboration to fund new schemes
Hydro-Electricity generator	Water availability for energy production, value added	Best time-of-use considerations to maximise value of renewable energy	Supplier electricity, location for facilities, renewable energy, value added	Competition for water resources, New customer – revenue
Domestic hydrogen gas customers	Availability of supply, low cost	Reduce price pressure for other/more traditional fuels	Customer	Revenue
Interstate / international hydrogen gas customers	Availability of supply, low cost	Source green hydrogen at lowest cost	Customer	Revenue
Water extraction planning / licencing authority	Regulator, water security	Sustainability, Resilience	Regulation	Additional pressure on water resources
Traditional custodians	Not known	Not known	Not known	Not known
Road / Rail / Port Operators	BAU supply chain	High/consistent volumes, safe transport	Provision of supply chain infrastructure	New customer

Table 2 Case study factors

Option	Description	Location / Water Source	Electrolyser Size (MW)	Green H2 Tech	Carrier	Cooling	Desal Tech	Brine Tech	Brine Disposal
1	Industry / Port based (Bell Bay Port)	Coastal	300	PEM - 75% efficiency	H2 gas	Evaporative	RO (two pass)	Outfall	Ocean
2	Industry / Port based (Bell Bay Port)	Coastal	300	PEM - 75% efficiency	H2 gas	Evaporative (direct seawater)	RO (two pass)	Outfall	Ocean
3	Industry / Port based (Bell Bay Port)	Coastal	300	PEM - 75% efficiency	H2 gas	Once Through	RO (two pass)	Outfall	Ocean
4	Midlands Irrigation Scheme	Inland Surface Water	300	PEM - 75% efficiency	H2 gas	Evaporative	RO (single pass)	Thermal ZLD - Power Driven	Landfill
5	King-Yolande Hydro Scheme	Inland Surface Water	300	PEM - 75% efficiency	H2 gas	Once Through	RO (single pass)	Outfall	Dilution (<0.1% conductivity change)

Table 3 Daily capacities for hydrogen production facilities

	Option 1	Option 2	Option 3	Option 4	Option 5
Intake capacity (ML/d)	14.7	16.3	269.2	6.3	267.5
Outfall capacity (ML/d)	7.9	10.1	268	0	266
RO plant capacity (ML/d)	14.37	3.56	3.56	1.80	1.80
Demin plant capacity (ML/d)	1.44	1.44	1.44	1.44	1.44
Blowdown plant capacity (ML/d)	-	-	-	1.01	-
Zero liquid discharge plant capacity (ML/d)	-	-	-	0.19	-

Table 4 Water efficiency in hydrogen production

	Option 1	Option 2	Option 3	Option 4	Option 5
Total raw water demand (L/kg H2)	107	119	1964	46	1952
Demin raw water demand (L/kg H2)	27	26	26	14	14
Cooling raw water demand (L/kg H2)	81	93	1938	38	1938
RO concentrate production (L/kg H2)	57.7	14.3	14.3	2.6	2.6
Mixed salt waste production (kg mixed salt / kg H2)	-	-	-	0.11	-