Could Multi-effect Distillation be the Key to Unlock Large-scale Solar Driven Green Hydrogen Production?

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Introduction

The production of green hydrogen via water electrolysis and renewable energy (such as solar PV) has long been touted as a sustainable, low-carbon alternative for hard-to-abate industries, which are currently reliant on fossil fuels [1]. However, the water requirements for green hydrogen production through such means, have largely been underestimated. To date, literature has mostly focused on the stochiometric water requirements of the electrolyser, estimated at ~10L of demineralised water per $\mathrm{kg_{H_2}}$ [2,3]. However, there has been less emphasis on the total water requirements related to electrolyser operation, such as the water losses surrounding the demineralisation process and the cooling requirements of the electrolyser units themselves [4,5].

A commercial proton exchange membrane (PEM) electrolyser, operating at 75-80% efficiency (HHV)[3], 60°C and 30bar pressure, generates an estimated ~9.6-12.8 $\mathrm{kW_{th}h}$ of heat for every kg of hydrogen produced. For commercially available electrolysers of sufficiently low capacity (~5-15MW capacity), this cooling demand can be managed through passive-cooling alone [6]. However, as this technology matures and the cost of manufacturing electrolysers decreases, we should expect to see electrolyser facilities with a 100 – 1000 MW (1GW) capacity within the next decade. For large-scale facilities of this nature, where passive-cooling may no longer be viable (particularly in areas with high ambient temperatures), more effective cooling techniques, such as cooling water towers, will need to be employed.

There are estimates that water-cooling requires 3 – 4 times the water that is needed for the electrolysis process to run [4,5], bringing the estimated water consumption rate of treated water up to ~30 – 50 L per kg_{H_2}, significantly higher than original estimates. As freshwater scarcity is of particular concern within Australia and is a necessary feedstock for crucial industries, such as agriculture, great importance must be placed on securing this resource for the green Hydrogen industry. One such means of ensuring water availability is through seawater desalination.

This study explores seawater desalination through conventional means, such as seawater reverse osmosis (SWRO) coupled with either passive-cooled or water-cooled electrolysers, or a novel approach of using low-temperature multi-effect distillation (LT-MED) driven by the electrolyser waste heat. A numerical model was developed to determine the effect of each operating regime on the levelized cost of water (LCOW) and hydrogen (LCOH). The analysis was then extended up to a hypothetical 1 GW electrolyser facility to see how the economies of scale affect the economic viability of large-scale projects.

Our findings suggest that LT-MED can not only produce desalinated water at a lower levelized cost than the other operating regimes, electrolyser facilities operating with LT-MED have much lower water demands due to water savings of not having to install and operate cooling water towers in addition to the desalination process. In addition, our modelling suggests that LT-MED can produce as much as 50-100L of excess desalinated water per kg_{H_2} produced, providing a convenient co-generation opportunity for this industry.

Methodology

This study investigated the water requirements of operating a commercially available 17.5 MW PEM electrolyser (Siemens Silyzer 300) [6] and a hypothetical 1GW PEM electrolyser of equivalent performance. The analysis was based on 3 different configurations: (1) SWRO with passive-cooled electrolysers (see Figure 1 (a)), (2) SWRO with water-cooled electrolysers and Cooling Water Tower (see Figure 1 (b)), and (3) LT-MED using the waste heat of the electrolysers (see Figure 1 (c)).

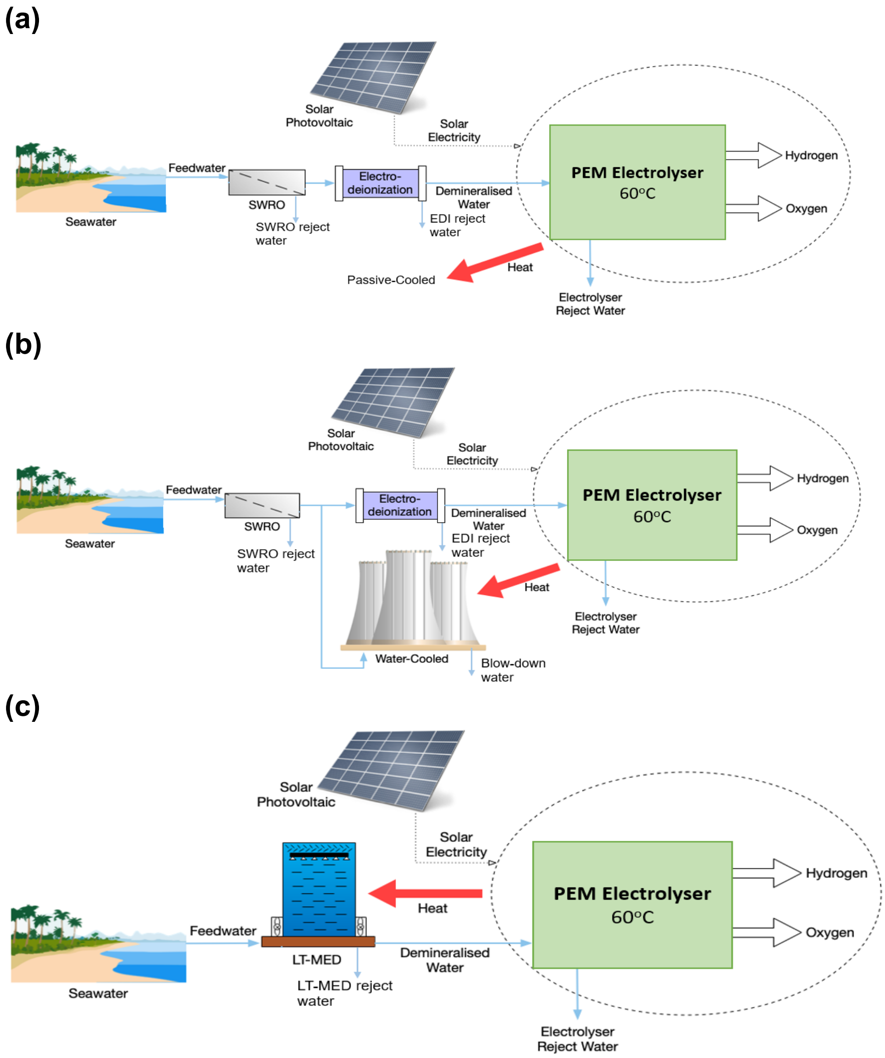

Figure 1: (a) SWRO with passive-cooled electrolysers; (b) SWRO with water-cooled electrolysers and Cooling Water Tower; (c) LT-MED using the waste heat of the electrolysers

Water requirements for each process were determined using a bottom-up analysis. The associated water treatment plant capacities were then determined based on these (refer to Table 1). The LT-MED process was simulated in Matlab using an in-house model developed by the co-authors [7]. Heat rates for cooling requirements were based on reported electrolyser efficiency and hydrogen's High Heat Value (HHV) with a 50% margin to account for any assumptions surrounding produced heat and available heat to our process.

Table 1: Design conditions for each system arrangement

PEM Electrolyser *Peak Capacity*	**System Arrangement**	**Water Treatment Plant (WTP) Sizing Subject to**	**Water Treatment Plant (WTP) *Peak Capacity***
17.5MW (1GW - hypothetical)	SWRO + Passive-cooling	Water demand of Electrolysers	100 m^3/day (5,700 m^3/day)
	SWRO + Cooling Towers	Water demand of Electrolysers + Cooling Towers	235-360 m^3/day (13,600-20,600 m^3/day)
	LT-MED (using waste heat)	Cooling Demand of Electrolysers	485-915 m^3/day (27,700-52,300 m^3/day)

The levelised cost of water (LCOW) was determined using a cash flow analysis based on the capital expenditure (CAPEX) and operating expenditure (OPEX), as shown in the equation below:

$$LCOW_{\frac{\$AUD}{m^3}} = \frac{Annuitised\ CAPEX + Fixed\ OPEX + (Variable\ OPEX * CapacityFactor * PlantAvailabilty)(\$AUD)}{Produced\ Water\ (m^3)} \quad \text{Eq. (1)}$$

The cost parameters used to calculate the LCOW are summarized in Table 2, where the impact on the levelized cost of hydrogen was determined using the HySupply tool [8].

Table 2: Cost parameters

Parameter	**Value**
Discount Rate	7%
Plant Availability[1]	95%
Capacity Factor[2]	20-30%
Project Life	25 years

[1] Plant Availability accounts for process down-time due to malfunction / maintenance
[2] Capacity Factor accounts for intermittent operation due to intermittent energy input

Preliminary Results

Figure 2 shows the effect of the intermittent operation on the levelized cost of water for the proposed configurations for a 17.5MW electrolyser facility, as well as the percentage of LCOH cost attributed to water for each scenario. Furthermore, each simulation was repeated for the hypothetical case—1GW system to see what effect the economies of scale had on these configurations. As expected, large-scale facilities operating full-time gave the lowest LCOW.

The LT-MED process holds two main advantages over SWRO. The first is that the energy for desalinating water is effectively 'free', coming as waste heat from the electrolysers. The second is that the LT-MED itself acts as the heat-sink for the cooling water circuit, evading the need to install cooling water towers at these facilities.

However, these advantages also come with challenges. The LT-MED is sized based on the cooling demand of the electrolyser facility, not the water demand. This results in an excess water production of approximately 50-100 L of desalinated water per $\mathrm{kg_{H_2}}$ from these facilities, which must be on-sold for the LCOW calculations to hold. Another, more notable challenge is that the operation of the electrolyser facility dictates the operation of the LT-MED process. For instance, any intermittent operation of the electrolyser facility is directly reflected as intermittent operation of the LT-MED process. On the other hand, configurations that utilize SWRO can be sized and operated independently of the electrolyser facility, providing far more flexibility in terms of desalinated water capacity and its operation.

The results illustrate that the water requirements for solar-driven green hydrogen can be met with either SWRO or LT-MED with minimal impact on the final cost of Hydrogen. Both processes can produce water at a similar LCOW (Figure 2); however, water has a smaller impact on the LCOH for systems operating with LT-MED or SWRO with passive cooling. This is due to the reduction in water demand for these systems (requiring 10-12 $\mathrm{L/kg_{H_2}}$) compared to systems operating with SWRO and cooling towers (which require 30-50 $\mathrm{L/kg_{H_2}}$). The use of LT-MED thus provides a convenient cogeneration opportunity for this industry, provided there is a suitable consumer for the surplus desalinated water.

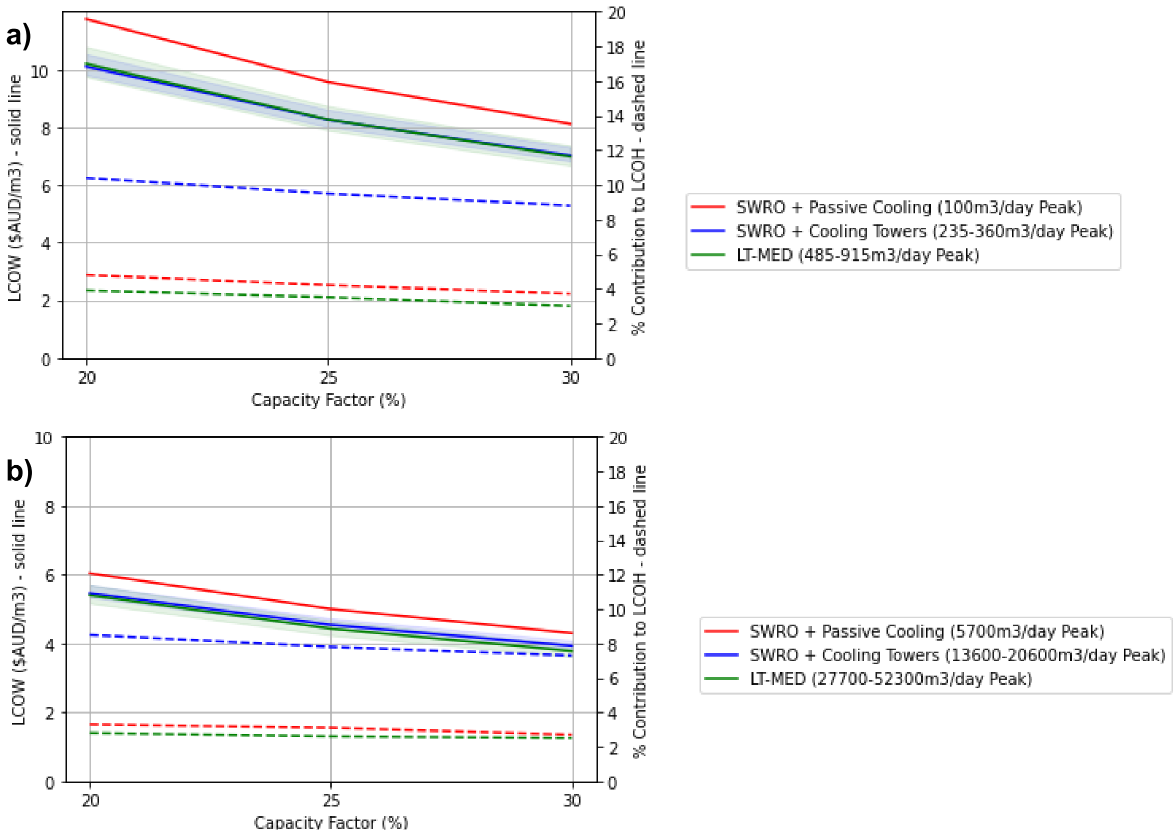

Figure 2: Intermittent operation effect on the levelized cost of water (LCOW) - solid line, and the contribution this has to the levelized cost of hydrogen (LCOH) - dashed line, for each proposed configuration (a) 17.5MW facility (b) 1GW hypothetical facility

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