Green Hydrogen from Treated Wastewater via SOECs: A Pathway to Circular Economy and Renewable Energy Integration

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Significance and Relevance

This study demonstrates that Solid Oxide Electrolysis Cells (SOECs) can produce green hydrogen from treated municipal wastewater, presenting an innovative solution to reduce reliance on pure water sources and enhance sustainability. By optimizing thermal energy recovery, the system achieved an efficiency of 85%, generating up to 26.2 kg of hydrogen per cubic meter of wastewater. This novel approach could cover up to 20% of Italy's 2030 energy needs, highlighting SOECs as a feasible technology for circular economy applications in hydrogen production.

Preferred and 2nd choice for the topic:
1st choice: H_2 storage and transportation, green H_2 production, hydrogen vectors;
2nd choice: Water treatment.
Preferred presentation: Oral preferred or Short Oral

Introduction and Motivations

In pursuit of the European Union's goal of carbon neutrality by 2050, green hydrogen (H_2) has gained significant interest as a low-emission fuel capable of supporting renewable energy storage, decarbonizing industrial processes, and reducing fossil fuel dependency[1]. Among available electrolysis technologies, **S**olid **O**xide **E**lectrolysis **C**ells (**SOEC**s) offer unique advantages for sustainable hydrogen production due to their high efficiency, capability to operate at elevated temperatures, and tolerance to lower-purity water sources[2,3]. This study explores the viability of treated municipal wastewater as a feedstock for **SOEC**s, providing a sustainable alternative that preserves freshwater resources. By utilizing impure water sources and recovering energy efficiently, **SOEC**s not only offer a pathway to green hydrogen production but also support circular economy principles through wastewater reuse.

Materials and Methods

Four distinct wastewater streams from Northern Italian municipal **W**aste**W**ater **T**reatment **P**lants (**WWTP**s) were analyzed, each with unique characteristics, such as population capacity, industrial load, and treatment methods. The wastewater samples were pre-treated, and pollutant concentration levels were assessed against Italian regulatory limits for discharge into surface water and public sewers. Using the *Aspen Plus* simulation platform, the **SOEC** process was modeled with a focus on the evaporative potential of each wastewater stream, as well as the thermal integration within the **SOEC** stack to minimize external energy input. The **SOEC** model included energy and mass balance equations for heat exchangers and split junctions, taking into account temperature, mass flow, and electrochemical reactions within the cell. This simulation framework enabled the estimation of hydrogen production efficiency, energy consumption, and potential environmental impact.

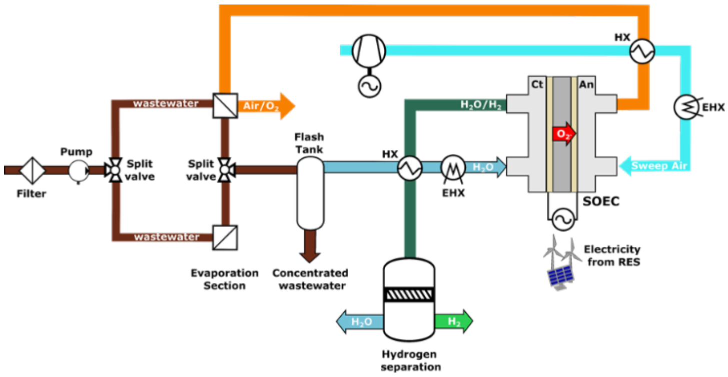

***Figure 1**. Layout of the SOEC stack.*

Results and Discussion

This study demonstrates that treated municipal wastewater from various WWTPs, differing in capacity, industrial load, and treatment methods, can serve as an effective and sustainable water source for SOEC-based green hydrogen production. With the European Union's energy transition goals, Italy aims to install 5 GW of electrolysis capacity by 2030, and wastewater-fed SOECs present a promising strategy to meet this target by reducing dependency on high-purity water sources.

In the Best-case Scenario (BS), where the SOEC operates for 7,500 hours annually with a moderate power setting of 2.12 V and supported by a mix of wind and conventional energy, two WWTPs were evaluated for their potential hydrogen contributions. WWTP C, with a capacity of 120,500 population equivalent (P.E.), an average flow rate of 27,500 m^3/day, and an industrial load of 11%, could produce 0.10 Mt/y of hydrogen, equating to roughly 15% of Italy's national target. Meanwhile, the larger WWTP A, with a capacity of 620,600 P.E., a flow rate of 155,300 m^3/day, and a 15% industrial load, could generate 1.46 Mt/y of hydrogen—well above the national goal. Even under a more constrained scenario (Worst-case Scenario, WS), where SOEC operation relies solely on wind energy and is limited to 2,000 hours annually, WWTP A still shows a significant output with 0.39 Mt/y of hydrogen, while WWTP C contributes 0.03 Mt/y.

Converting these hydrogen outputs into potential electricity contributions highlights the substantial role that wastewater-based SOECs could play in Italy's future energy landscape. Meeting Italy's projected electricity demand growth in 2030 will require the addition of 8.6 to 10.7 GW of new capacity per year. Under BS conditions, WWTP A alone could fulfill 20% of this additional capacity requirement, while it could still meet 5.4% in the WS. Similarly, WWTP C could supply 1.3% in the best scenario and 0.4% in the worst scenario. These findings underscore the significant renewable energy potential of wastewater-fed SOECs, supporting Italy's transition toward a sustainable and decarbonized electricity grid.

References

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Acknowledgements

The authors thank the European Union for funding this research through the NextGenerationEU program under the PROMETH2eus project.