Integrated approach to brine valorisation and biomethane production using waste streams: techno-economic analysis and challenges

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The recovery of valuable resources from waste streams is gaining increasing attention for its potential to contribute to both environmental sustainability and economic benefits. In this context, there is an increasing emphasis on resource recovery from desalination of brine streams, aligning with the urgency for environmental sustainability, particularly in the context of addressing global water scarcity challenges (The Sustainable Development Goals Report 2023).

Desalinated water is recognized as a key solution for addressing water scarcity issues by providing an additional source of freshwater beyond what is available through natural processes like the hydrological cycle.

Globally, a significant number of operational desalination plants are producing considerable volumes of desalinated water. Reverse osmosis (RO) is identified as the dominant desalination process, constituting a large percentage of operational plants (Baudino, 2022).

A notable challenge associated with seawater (SW) desalination process, particularly RO, is the generation of concentrated brine. The information underscores that globally, desalination plants are estimated to generate a substantial volume of brine, approximately 124.5 million m^3/day.

This brine is often treated as waste and disposed of into the coastal oceanwaters, raising environmental concerns. The impact of brine discharge on marine ecosystems, including potential harm to aquatic life and ecosystems, is an important consideration in the sustainability of desalination processes.

In this context, the recovery of metal resources from seawater desalination brine presents a promising avenue. Metals such as lithium, magnesium, and other valuable elements can be extracted from the brine, offering an additional incentive for the sustainable management of desalination by-products.

Lithium, a crucial component in the battery industry for electric vehicles and electronic devices, is often present in desalination brine (U.S. Geological Survey, Mineral Commodity Summaries, January 2023). Developing technologies for efficient lithium extraction can contribute to the growing demand for renewable energy storage solutions.

The present work can provide valuable insights into the potential of metal resource recovery from seawater desalination brine adopting the "treating waste with waste "strategy (Guo, 2020), emphasizing both the technical and economic aspects.

Here an innovative approach to brine treatment chain shown in Figure 1, is examined. The process involves a biomethanation unit fed with CO_2 and digestate produced by anaerobic digestion plants, H_2 from solar powered water electrolysis and brine from SWRO desalination plant as proposed in the perspective by Abdel Azim (2023). Different scenarios of the proposed are herein considered, and their implications are examined in a comprehensive technoeconomic analysis.

Despite being a pioneering study in this field, there are still several limitations to the analysis developed here, and its large-scale development requires careful consideration of economic and environmental implications.

In particular, the process intermediate consists of microbial biomass bearing the metals of interest which might be absorbed to the cell surface through biosorption mechanisms as well as accumulated into the cell by active transport systems. Moreover, it is important also to consider the possibility that metal precipitation could occur due to the presence of organic matter proper of the digestate acting as sorbent materials (Madeła, 2021).

This study aims to provide valuable insights into the potential of integrating biomethanation processes into the treatment of desalination brine, with an emphasis on both technical feasibility and economic viability. The findings are expected to contribute to the advancement of sustainable desalination practices and the broader field of resource recovery. The techno-economic analysis critically assesses the proposed method against existing brine treatment technologies, drawing on recent comparative studies like Morgante (2022). This analysis is paramount in not only determining the technical feasibility and environmental sustainability of the proposed method but also in evaluating its economic viability. It encompasses a comprehensive examination of technical parameters such as inlet flow rate, ions concentrations, and products generations, alongside economic factors including energy consumption, capital and operational expenditures. The analysis thus provides a dual perspective on operational efficiency and market competitiveness, which is vital for the commercial success of new technologies.

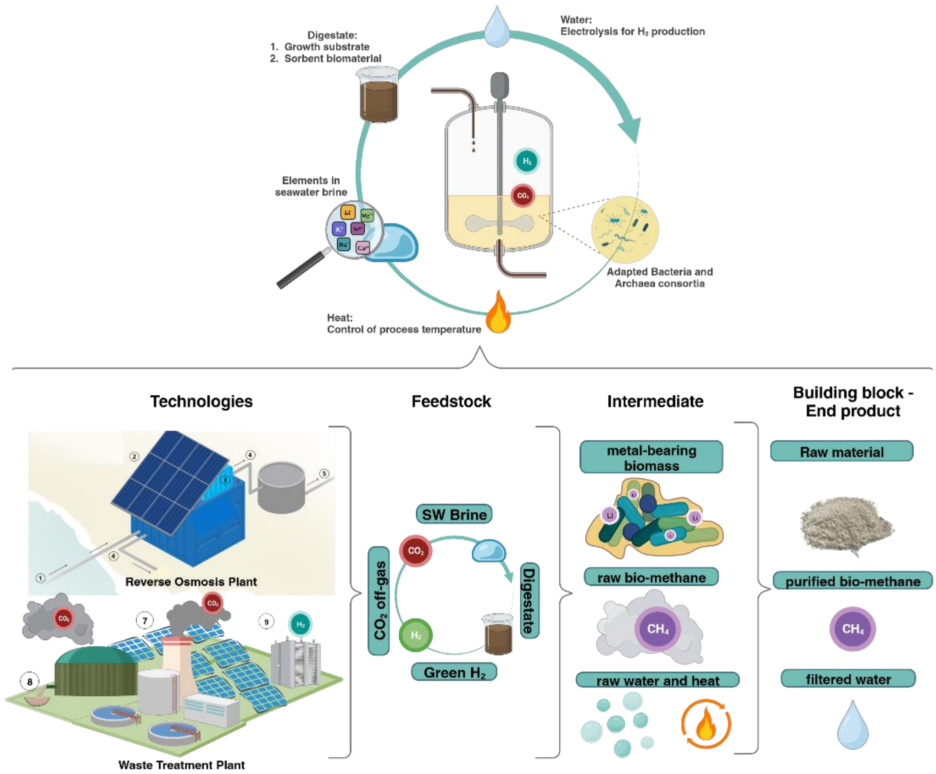

Figure 1 Concept and circularity of the proposed process for brine treatment via biomethanation. The top panel describes the recycle of some raw materials and products within the process. The down panel shows the feedstock, intermediate and building block/end-product considered for the techno-economic analysis. Technologies are also represented to give a comprehensive view of the process framework. Legend: 1. Seawater intake, 2. Solar desalination, 3. Clean water storage, 4. Piping, 5. Water use, 6. Brine from desalinated seawater, 7. CO_2 off gas streams from anaerobic digestion (AD) plant and industrial manufacturing, 8. Anaerobic digestate form AD plant, 9. H_2 generation by water electrolysis powered by sun. SW: Seawater

The comparative aspect of this analysis is particularly enlightening, revealing how different technologies stack up in terms of technical efficiency and economic feasibility. For instance, the comparison with emerging technologies such as nanofiltration, ionic exchange membranes, electrodialysis (Baudino, 2022) provides valuable insights into operational effectiveness, potential scalability, and economic viability, which are crucial for making informed decisions about technology adoption.

Several scenarios were explored, considering different feedstocks and operational conditions, to assess the scalability and economic implications of the proposed biomethanation process.

In conclusion, the study reports a comprehensive techno-economic analysis that investigate the feasibility and limitations related to the scalability of biomethanation process for brine valorisation in a circular biobased approach, emphasizing a closed-loop system that maximizes the utilization of wastes as resources within the cycle. By comparing this innovative approach with other existing technologies, we aim to contribute significantly to sustainable desalination practices and open new pathways for resource recovery. This analysis aligns with global sustainability goals, highlighting the potential for capitalizing waste in an economically viable and environmentally sustainable manner.

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