



# UNLOCKING THE POTENTIAL OF DESALINATION BYPRODUCTS

WHITE PAPER

Brine Mining

# Introduction

**Brine mining, the process of extracting valuable minerals from sea water desalination process by-product (brine), is gaining traction as a solution to the sustainable and economic challenges posed by brine disposal. With increasing desalination activities to address global water scarcity, the vast quantities of brine produced are a challenge and expensive to manage. However, this byproduct represents a significant untapped resource rich in minerals such as sodium chloride (NaCl), bromine, and magnesium among many others.**

This white paper follows ENGIE's Catalyst Connect on Brine Mining, where industry experts explored the motivators behind the growing interest in brine mining, the challenges and opportunities it presents, and the steps required to turn this concept into a viable reality. A key consideration was whether brine management should be integrated into desalination, treating brine as a resource rather than waste, enabling plants to become circular water hubs that extract valuable minerals like lithium and but also chemicals that can be re-used in

the desalination process while reducing environmental impact. Alternatively, brine management could be handled separately by companies with expertise in mineral extraction, and main industrial users of those minerals, ensuring optimized recovery processes but potentially limiting synergies with desalination. The decision on integration will shape the future of sustainable water and resource management, influencing business models, policy frameworks, and technological advancements in the desalination industry.



# Why Brine Mining? Motivators and Context

The seawater desalination process produces brine, a concentrated saline solution, typically discharged following strict standards to ensure proper dilution. However, rather than treating brine as a byproduct, should we view it as a resource, rich in valuable minerals and salts. By leveraging the desalination process to further concentrate brine, we can optimize

mineral extraction. Adopting a circular approach to desalination could transform brine into a secondary resource, unlocking new economic and sustainability opportunities through mineral recovery and resource utilization.

## KEY MOTIVATORS

- **Regulatory Drivers:** Brine reject and its recirculation into the desalination plant is the most challenging piece in the decision to integrate brine management into desalination or develop parallel industrial activities hinges on key factors, particularly regulatory drivers. Governments and international bodies are increasingly prioritizing circular water solutions, pushing for zero-liquid discharge (ZLD) policies and incentivizing brine valorization through green financing frameworks. By recognizing brine as a strategic resource rather than non-usable by-product, desalination plants could evolve into integrated water-mineral hubs, unlocking new revenue streams while reducing reliance on raw material extraction. Regulatory alignment will be critical in shaping whether this transformation occurs within the desalination industry or through specialized industrial partnerships.
- **Economic Opportunity:** Minerals extracted from brine can meet global demand, providing an alternative to depleting resources such as surface salt mines. For example, in Malaysia, a 99.6% purity NaCl costs \$30 per tonne to produce, but can sell for \$120 per tonne.
- **Water-Energy Nexus:** Brine mining aligns with sustainability goals, transforming desalination plants into multi-resource hubs that integrate water, mineral production circularity and zero waste.
- **Strategic Resource Management:** Addressing resource depletion, such as declining surface salt mines in Saudi Arabia.

## CHALLENGES AND THE CATCH-22 OF BRINE MINING

Despite its potential, brine mining faces significant hurdles:

### Technological Maturity

Current technologies struggle to efficiently and economically concentrate and extract minerals from brine:

- Selective membranes achieve concentrations of 75 g/L.
- Brine concentrators reach 120 g/L, while ultra-brine concentrators achieve 220 g/L, approaching NaCl saturation.
- High temperatures and variable salinity challenge membrane durability and performance.

Moreover, the technical maturity of brine mining remains a significant barrier to scaling these solutions. While existing methods have shown promise, they lack the efficiency and cost-effectiveness required for widespread adoption on a large scale.

Challenges include optimizing energy consumption, improving material durability to

withstand extreme conditions, and developing methods to selectively recover high-value minerals without contaminating by-products. Technologies, such as advanced ion-exchange systems and electrochemical processes are developed, however are still maturing for brine mining applications before integration into industrial desalination workflows. Scaling up these solutions also comes with significant operational costs, currently hindering economic viability, making it essential to drive technological advancements, process efficiencies, and regulatory incentives to bridge the gap between innovation and large-scale implementation.

This technological gap underscores the need for collaborative innovation to make brine mining a commercially viable and sustainable option.

### Economic Viability

The desalination industry operates on long-term Water Purchase Agreements (WPAs), often spanning 25-30 years. In contrast, mineral markets are volatile, complicating efforts to align mineral offtake agreements with stable financial structures. Unlike the predictability of WPAs, the mineral market's fluctuating demand and pricing make it challenging to secure the long-term commitments necessary to mirror the financial stability of desalination.



## Scale and Proof of Concept

Brine mining requires large-scale operations to become economically viable. Initial small-scale projects must demonstrate feasibility and reliability to confirm the potential of such industry. These pilot projects play a crucial role in showcasing the technical capabilities, performances, economic potential, and environmental impact of brine valorization. By proving the viability of extracting valuable minerals sustainably, small-scale initiatives can build confidence among investors, policymakers, and industry leaders.

Additionally, successful demonstration projects can pave the way for developing standardized processes, reducing costs, and

addressing potential risks associated with scaling up operations. Collaboration between technology developers, government, financial institution, regulatory entities, and desalination operators will be essential in overcoming barriers to adoption. Furthermore, aligning small-scale projects with global sustainability goals, such as promoting circular economies, can create a compelling narrative to secure funding, regulatory support, and public trust.



## Stakeholder Alignment

Brine mining's success will require a collaborative approach that extends far beyond the desalination industry. Achieving scalability and economic viability demands alignment across diverse stakeholders, including governments, mineral markets, potential offtakers, and industry players.

- Manufacturers and industrial users of extracted minerals demand consistent quality and steady supply volumes to support their production processes. Can brine mining technologies meet these stringent standards while ensuring supply reliability?
- Engineering, Procurement, and Construction (EPC) contractors play a critical role in implementing brine valorisation plants. They require risk-sharing incentives for pilot and large-scale projects, such as shared

financial liability or long-term supply agreements, to justify the investment in innovative, unproven technologies. Know-how remains a key on project finance schemes.

- Governments are pivotal in creating regulatory frameworks, offering incentives, and supporting public-private partnerships. Policies that promote the sustainable use of resources, coupled with green financing mechanisms, can attract investment and mitigate risks for early adopters.
- Banks and investors need robust business cases underpinned by stable demand for minerals and reliable supply chains. The inclusion of environmental and social benefits, such as contributing to circular economies, can strengthen the value proposition for financiers.

## PATHWAYS TO MAKE BRINE MINING A REALITY

To bring brine mining into practical application, several elements must align:

### Technological Advancements

- Mineral Extraction Membranes:** Developing next-generation membranes specifically designed for selective mineral extraction is key to unlocking brine's full potential. These membranes must exhibit high ion selectivity, durability, and resistance to extreme conditions, including high temperatures and variable salinity levels, to ensure efficient and scalable recovery of valuable minerals. Unlike traditional desalination membranes, these advanced membranes should be tailored to separate and concentrate specific elements, such as lithium, magnesium, and potassium, without excessive fouling or degradation. Innovations in functionalized polymers, graphene-based structures, and nanostructured membranes could enhance separation efficiency, extend operational lifespans, and lower maintenance costs, making large-scale brine mining more viable and economically sustainable.
- Modular Systems:** Design modular brine concentration units that seamlessly integrate with existing reverse osmosis (RO) infrastructure. These systems would allow desalination plants to adapt incrementally, optimizing brine management without requiring a complete overhaul. Modular designs also offer scalability, enabling facilities to expand operations in response to demand or market opportunities.
- Crystallization Processes:** Develop innovative crystallization techniques that efficiently extract high-purity minerals from brine. Leveraging controlled temperature and pressure systems, these methods can enhance yield while minimizing energy consumption. Emerging technologies such as ultrasonic and membrane-based crystallization or electrochemical precipitation could provide breakthroughs in producing valuable minerals like lithium, magnesium, and rare earth elements.

### Proof of Concept

**Pilot Projects:** Launch strategically designed small-scale projects to rigorously test and validate both technical and economic feasibility. These pilots serve as critical proving grounds, enabling the optimization of brine mining technologies and processes while

minimizing risks. Focused efforts in diverse operational environments can highlight adaptability and scalability, creating a blueprint for larger implementations.

## Market Alignment

- **Commodity Market Engagement:** Strategically engage with the commodity market by identifying stable, high-value minerals such as lithium, bromine, or rare earth elements that offer consistent demand. Develop innovative and flexible contract structures, such as indexed pricing or hybrid agreements, to mitigate the impact of market volatility. By fostering partnerships with industries that prioritize sustainability, brine valorization operations can secure steady revenue streams while aligning with global trends toward responsible resource management.
- **Offtake Agreements:** Establish mineral offtake agreements that are carefully aligned with the long-term Water Purchase Agreements (WPAs) of desalination plants. This synchronization ensures predictable cash flows and reduces financial risks for both parties.

Structuring agreements with staggered timelines, performance incentives, and sustainable approach benchmarks can further enhance their attractiveness, creating a balanced, mutually beneficial framework for sustainable mineral extraction and desalination operations.



## Regulatory Support

- **Green Financing:** Position brine mining as a key component of the sustainable resource economy, advocating for its inclusion within green financing frameworks. Highlight its parallels to carbon management in energy projects, emphasizing its potential to enhance sustainability, promote circular economies, and recover valuable resources from industrial processes. By framing brine mining as a sustainable transformative solution, the industry can attract investments from green bonds, sustainability-linked loans, and other eco-focused financial instruments.
- **Environmental Standards:** Collaborate with regulatory bodies, environmental organizations, and industry stakeholders to establish robust and transparent environmental standards for brine mining construction and operations. These standards should address critical areas such as salinity management, ecosystem preservation, and waste minimization. Clear, enforceable guidelines will not only ensure sustainable practices but also bolster public trust and confidence in brine mining as a responsible and environmentally friendly solution.



## Stakeholder Collaboration

- Partnerships:** Forge strategic alliances with industrial players to integrate on-site mineral extraction and refinement capabilities. By co-locating these processes with desalination plants, operators can streamline logistics, reduce operational costs, and ensure that the extracted minerals meet the specific quality and quantity requirements of end-users. Such partnerships can also accelerate the adoption of brine mining by demonstrating its economic and environmental benefits to key industries, including infrastructure, pharmaceuticals, and agriculture.
- Incentives:** Design innovative performance-based contracts and risk-sharing models to attract and engage EPC (Engineering, Procurement, and Construction) contractors. These incentives could include milestone payments, revenue-sharing agreements, or reduced upfront costs tied to project success metrics. By aligning the interests of contractors with long-term project goals, these models ensure a collaborative approach to overcoming technical challenges and scaling up operations effectively.
- Government Backing:** Actively seek support from governments and financial institutions to catalyse pilot projects and larger-scale implementations. Highlight the alignment of brine mining with national sustainability agendas, such as reducing construction, environmental impacts and promoting resource efficiency. Secure grants, subsidies, or low-interest loans to de-risk initial investments, and collaborate with policymakers to establish favourable regulatory that encourage innovation and long-term viability.

# Case Study

## Potential in the Middle East

A desalination plant processing 200,000 m<sup>3</sup>/day could produce approximately 1.8 million tonnes of NaCl annually. If production costs can be reduced below market prices, brine mining can become a lucrative revenue stream. With its high concentration of desalination plants, the Middle East is well-positioned to lead this initiative.

### **Toward a Sustainable Future**

Brine mining has the potential to transform desalination market and processes into multi-resource hubs, contributing to the circular economy. By addressing technological, economic, and sustainability challenges, and fostering collaboration among stakeholders, this untapped resource could become a cornerstone of sustainable development.



# Conclusion

## Unlocking the Promise of Brine Mining

Brine mining stands at the intersection of innovation, sustainability, and economic opportunity. By reimagining desalination byproducts as a valuable resource, it has the potential to address and unlock new revenue streams, and support global sustainability goals. Transforming brine into a cornerstone of the circular economy requires a multi-faceted approach, including advancements in technology, alignment with volatile markets, and collaboration across industries, governments and financial institutions.

The road ahead is not without challenges, from achieving technological maturity to ensuring economic viability. Yet, with strategic pilot projects, robust stakeholder alignment, and a commitment to sustainable practices, brine mining can redefine the role of desalination plants as multi-resource hubs.

Regions like the Middle East, with their high concentration of desalination plants and constant goal to achieve sustainable imperatives, imperatives, are uniquely positioned to lead this transformation.

### References

Text

This is a call to action for all stakeholders to governments, industries, researchers, and financiers to invest in the untapped potential of brine mining. The question remains: Should desalination and brine mining be part of the same business, or will they evolve as separate industries? As we advance technology, regulatory frameworks, and economic models, will future desalination projects inherently include mineral extraction, or will specialized industrial players take the lead? By addressing these uncertainties now, we can shape a future where desalination and brine valorization either merge into a circular water economy or develop as distinct yet complementary industries, driving sustainability, stewardship, and long-term economic prosperity.





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