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Paving the way for the future of mining

PERSPECTIVE

In-Situ Leaching: A Look into the Future of Heap Leaching

DECEMBER, 2023

ISL APPLICATION IN MINING

IN SITU ISL

FUTURE OF THE ISL METHOD

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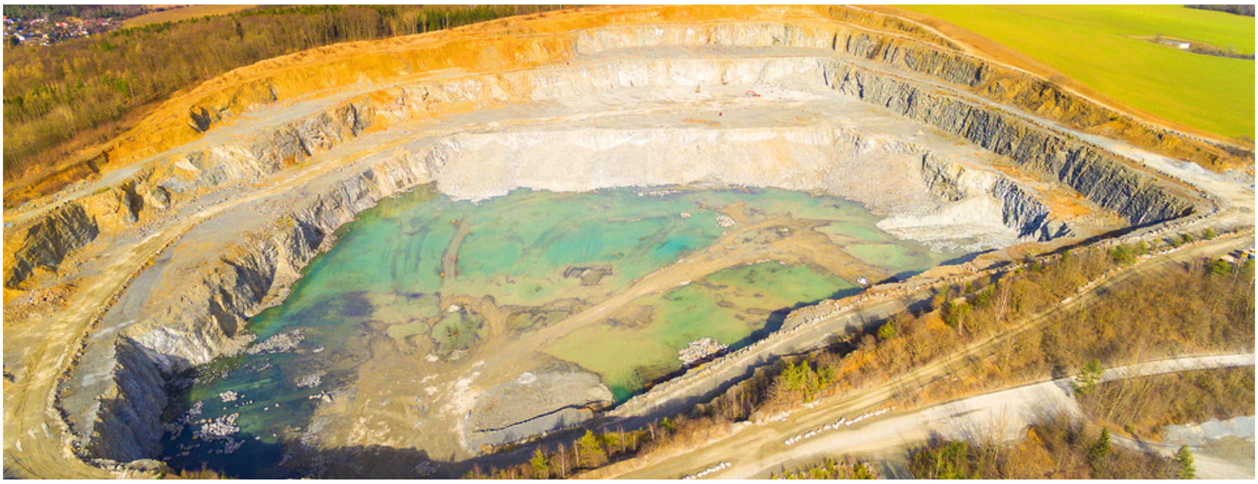

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We are an industrial engineering company whose focus is to support the mining industry in management and economics. We have six business areas, which encompass all our experience, while we develop the most advanced tools applied in mining. We have sucessfully implemented more than 400 projects worldwide in more than 14 years.

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EDITORIAL

Since its inception, the mining industry has been in constant pursuit of more efficient and sustainable processes and technologies. This has led to the development of innovative techniques that challenge traditional practices. *In situ* leaching stands out as a silent revolution with the potential to transform the way minerals are extracted.
In essence, in situ leaching involves the dissolution of minerals directly in their natural location, without the need to extract large quantities of ore for processing.

This approach contrasts sharply with conventional methods, which involve extracting millions of tonnes of ore for transportation by trucks, railways, pipelines, or belts to processing plants located considerable distances from the mine.

One of the most notable benefits of *in situ* leaching is its lower environmental impact. By avoiding extensive excavation, emissions of greenhouse gases associated with material transportation are drastically reduced. Additionally, soil impact is minimized, preserving local ecosystems and preventing landscape degradation. This technique closely aligns with the increasingly crucial requirements of sustainability and environmental responsibility in modern mining.

Another key aspect is operational efficiency. *In situ* leaching significantly reduces costs associated with blasting, transportation, crushing, and stacking large amounts of material.

However, challenges and concerns associated with *in situ* leaching cannot be overlooked. Proper management of water and chemicals used in the process is critical to avoid soil and groundwater contamination. Transparency and community involvement are essential to address local concerns and ensure that operations are socially responsible.

Juan Esteban Fuentes
Head Business Development

Continuous research and technological innovation are fundamental to overcoming these challenges and maximizing the benefits of in situ leaching. Collaboration among industry, academia, regulatory authorities, and local communities is essential to develop and implement best practices.

In summary, *in situ* leaching represents a bold step toward a more sustainable and efficient mining industry. Embracing this technique allows the mining industry to move towards a future where mineral extraction is less invasive and more harmonious with the natural environment.

Undoubtedly, we are witnessing a transformation in how we extract minerals from the earth, and *in situ* leaching could be a future alternative leading this shift towards more efficient and sustainable mining.

INTRODUCTION

Heap leaching is a technique widely used in mining to extract different types of minerals such as copper, gold, uranium, nickel, iodine, nitrates, among others. This method consists of extracting the ore by drilling and blasting, and then accumulating it on heaps by means of trucks. The heaps formed are irrigated on the surface with a leaching agent to dissolve the compounds of interest, the leached solution is drained to the bottom of the heap and transported through channels to the plant for mineral recovery (see **Figure 1**).

The trend of decreasing ore grades in mining has led to a significant increase in the costs of this method, since maintaining production - requires an increase in the amount of ore extracted and processed, which in turn leads to an increase in energy and water consumption, which implies a higher carbon and water footprint, waste generation, storage costs and associated risks (Karami, 2022).

Additionally, many gold and copper deposits that are found at great depth or contain low-grade ores are not profitable to mine by heap leaching due to the high costs associated with drilling, blasting and transporting the ore for extraction.

In recent years, environmental demands and concern for the development of sustainable mining have increased. The heap leaching method does not appear to be sustainable in the long term due to its tendency to significantly increase costs and its high energy and water consumption, in addition to being considered an invasive method in terms of land use and waste generation. Therefore, there is a need to investigate new technologies to address these problems.

FIGURE 1: HEAP LEACHING

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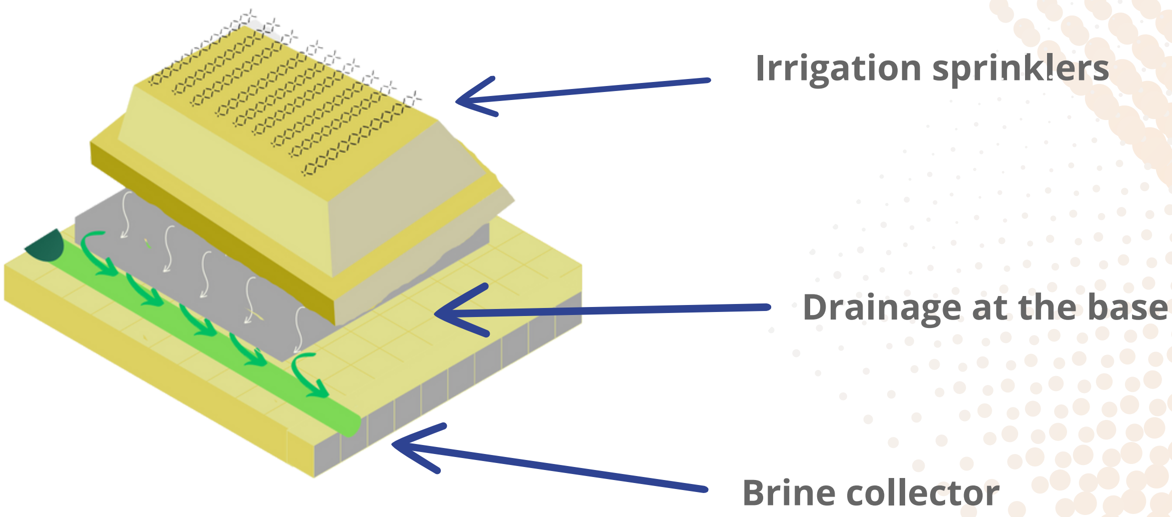


Source: GEM based on SQM (2023)

IN SITU LEACHING (ISL)

ISL is a method of dissolving and extracting ores directly in the deposit where they are originally found, without the need to extract and transport the ore to the surface. The leaching solution is pumped into the deposit through injection wells and then the leach solution is extracted through recovery wells. In addition, monitoring wells are used to control the operation and prevent soil and groundwater contamination, as the leaching solution often contains chemical reagents.

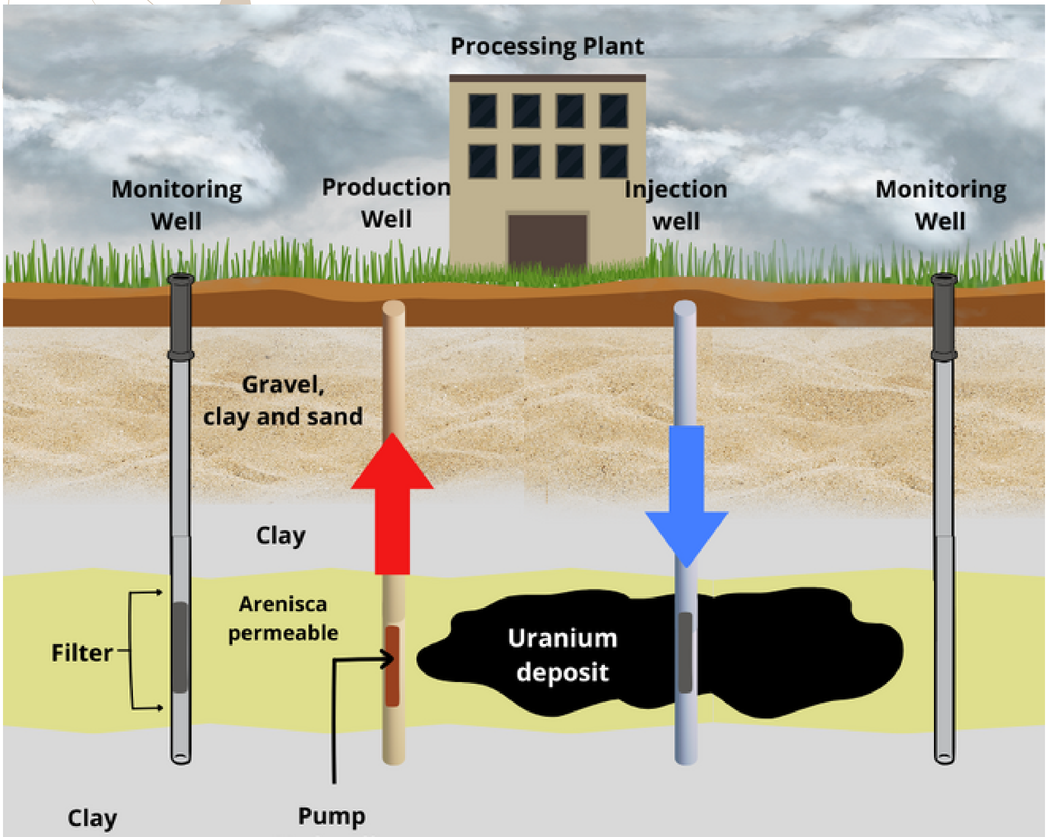
Finally, the leach solution is sent to the plant for metal recovery.

The ideal deposit to apply this method should have a high permeability, i.e., a high capacity to transmit fluids, in the ore body where leaching is performed to facilitate the flow of the injected solution and the leaching of the minerals.

Additionally, the subsoil strata delimiting the ore body should be impermeable, especially the lower stratum, as they serve as a barrier to isolate the leaching fluid and avoid contamination of aquifers, as well as loss of recovery efficiency.

This is the case of the uranium deposit and for this reason ISL is widely used for its extraction. **Figure 2** shows the leaching system and the characteristics of this deposit.

FIGURE 2: *IN-SITU* LEACHING IN URANIUM DEPOSIT



Source: GEM based on López (2021)

ISL applications in mining

ISL has been applied in uranium deposits in the United States using alkaline leaching systems and in the Soviet Union using acid leaching systems. The most common method is acid leaching which is also used in uranium mines in Australia. Uranium recoveries by ISL vary between 60% and 90% depending on the geology and leachant used (Karami, 2022).

Several industrial copper SIL projects have been implemented in the United States. However, only one of these was established on a commercial scale at San Manuel. Currently, Excelsior Mining is developing the **"Gunnison Copper Project" in southeastern Arizona**.

There are few commercial-scale ISL applications for copper, gold, and nickel, primarily because these ores are generally found in compact, impermeable rocks that make it difficult for leach to access the ore and limit contact between the leach solution and the ore (Karami, 2022).

Therefore, lower recoveries and longer leaching times are experienced compared to conventional leaching, which can make this type of mining unprofitable. However, recent advances in research related to techniques to increase the permeability of the porous medium and the leaching rate position ISL as a promising long-term alternative for the extraction of copper, gold, nickel and salts.

Benefits and limitations of the ISL method

As mentioned above, in a context where resource constraints and environmental awareness are of increasing relevance and concern, both in the mining industry and in society in general, ISL has attracted considerable interest. This technology is presented as an innovative solution to enhance the profitability and sustainability of the mining industry, and its development and adoption is expected to continue to increase due to its numerous benefits, in contrast to conventional heap leaching. The main benefits are presented in the following diagram.

IN SITU LEACHING BENEFITS

REDUCTION OF WATER CONSUMPTION

There would be less water consumption due to a lower evaporation rate of the leaching agent due to its underground action, decreased formation of flow paths due to less pore fracturing, and greater diffusion of the leaching agent due to the spreading plume injected by wells. This translates into a water footprint reduction and water consumption costs

REDUCTION OF VISUAL POLLUTION, CO2 EMISSIONS AND BETTER SPACE OPTIMIZATION

The ISL dispenses with the need to form piles and dumps on the surface, which implies the elimination of blasting, transport and piling processes, and therefore a significant reduction in CO2 emissions generated during the aforementioned processes

MINERAL RECOVERY IN UNPROFITABLE DEPOSITS WITH CONVENTIONAL LEACHING

Allows the extraction of minerals in low-grade, small and/or deep deposits, saving the high costs of excavation and considerably expanding the opportunities to exploit valuable resources

REDUCTION OF ORE PREPARATION AND DISPOSAL COSTS

By not requiring the use of heaps to leach the ore, there are no costs associated with blasting, transporting and stockpiling the material

LABOR COST REDUCTION AND SAFER WORKING CONDITIONS

Fewer operators are required, as the subway leaching process relies primarily on the operation of injection and recovery wells. As a result, working conditions are considerably safer as there are no heaps that could pose risks of accidents or collapse due to their height and surface exposure

LIMITING FACTORS *IN SITU* LEACHING

1 LOW EXTRACTION RATE AND RECOVERY LEVEL COMPARED TO THAT OBTAINED BY CONVENTIONAL LEACHING METHODS

Heap leaching generally allows a higher leaching rate due to a higher permeability and contact between the leaching agent and the ore due to the previous crushing of the material in the blasting process. In the same period of time, this results in higher ore recovery compared to ISL

2 LEACHING COSTS

The ISL includes costs associated with injection and recovery pumps and wells, which could involve high energy consumption. While in the heaps, leaching occurs by percolation, so the main cost is associated with the surface irrigation system

3 LIMITING FACTORS IN ITS APPLICABILITY ACCORDING TO THE HYDROGEOLOGICAL CONDITIONS OF THE RESERVOIR

For ISL to be feasible, it is necessary to have considerable hydraulic conductivity in the ore body of interest and low permeability in the adjacent strata, especially in the strata below the deposit

4 POSSIBLE GROUNDWATER CONTAMINATION AND DECREASED RECOVERY

The absence of impermeability in the strata bounding the ore body can lead to leaching of leach solution, which can compromise groundwater quality and negatively affect recovery performance. For this reason, it is important to have monitoring wells inside the deposit

Recognizing these limitations is fundamental to analyze the effectiveness of applying the ISL method according to the mineral to be extracted and the deposit in which it is located since the required leaching solution and the hydrogeological characteristics of the medium depend on these factors.

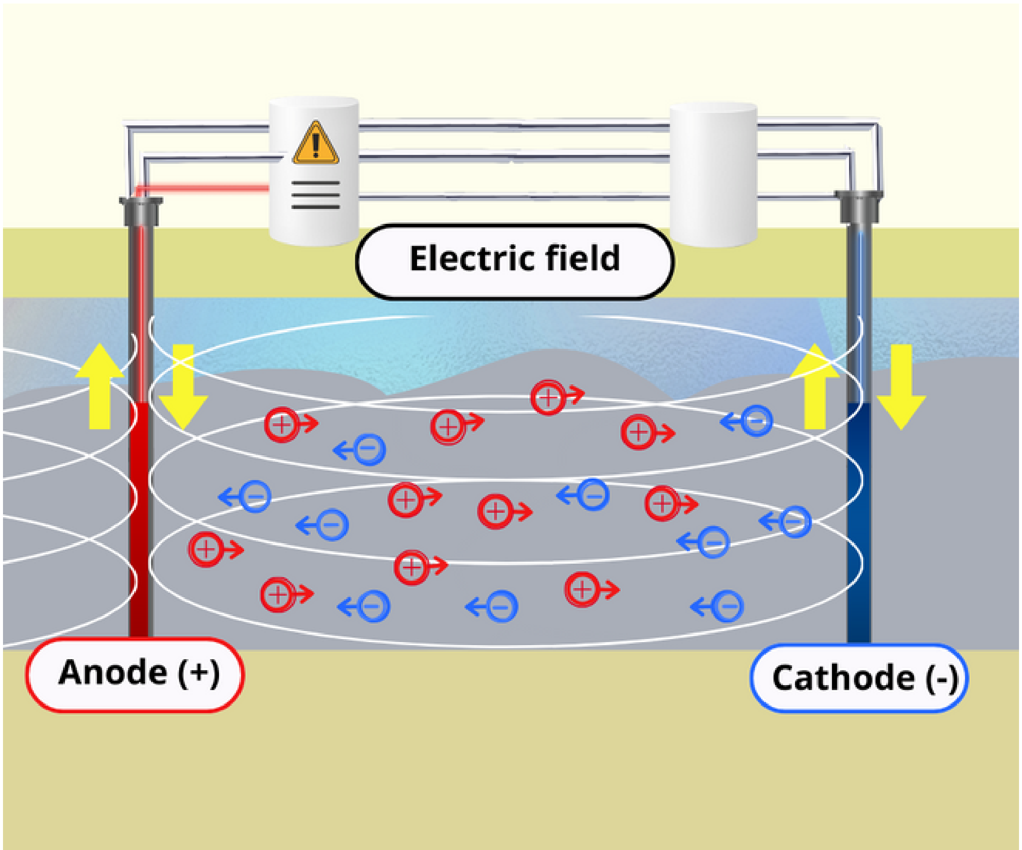
Complementary methods to ISL

For low permeability deposits one of the main limitations of the ISL method is that it may not be efficient in low permeability deposits, which is common in the case of gold and copper. However, to increase the mass transfer rate or rate at which fluid moves from one point to another in these types of reservoirs, modern methods such as electrokinetic, ultrasonic, pulsed solution mass transfer promotion or hydraulic fracturing could be used.

First, the electrokinetic transfer method consists of inducing ion migration by applying an electric potential difference. Two electrodes are installed inside the oppositely charged reservoir (a cathode and an anode), generating an electric field between them that promotes the movement of the ions contained in the minerals towards the oppositely charged electrode (see **Figure 3**).

This technique improves the mobility and transport of the metal ions through the porous medium, thus facilitating their recovery. For example, in experiments conducted by Voinitchi et al. (2008) it was found that the extraction rate by diffusion alone was approximately 20%, while using the electrokinetic transport method it was almost 74%.

FIGURE 3: ELECTROKINETIC MASS TRANSFER PROMOTION



Source: GEM base on World Energy Trade (2021)

One of the limitations of applying this technique is that energy consumption represents approximately 25% of the operating cost (Karami, 2022).

However, recent advances in renewable energy could offset this consumption. Another point to consider is the selection of the electrode material since its corrosion could lead to undesirable products in acidic environments and voltage losses at the electrode could result in additional costs.

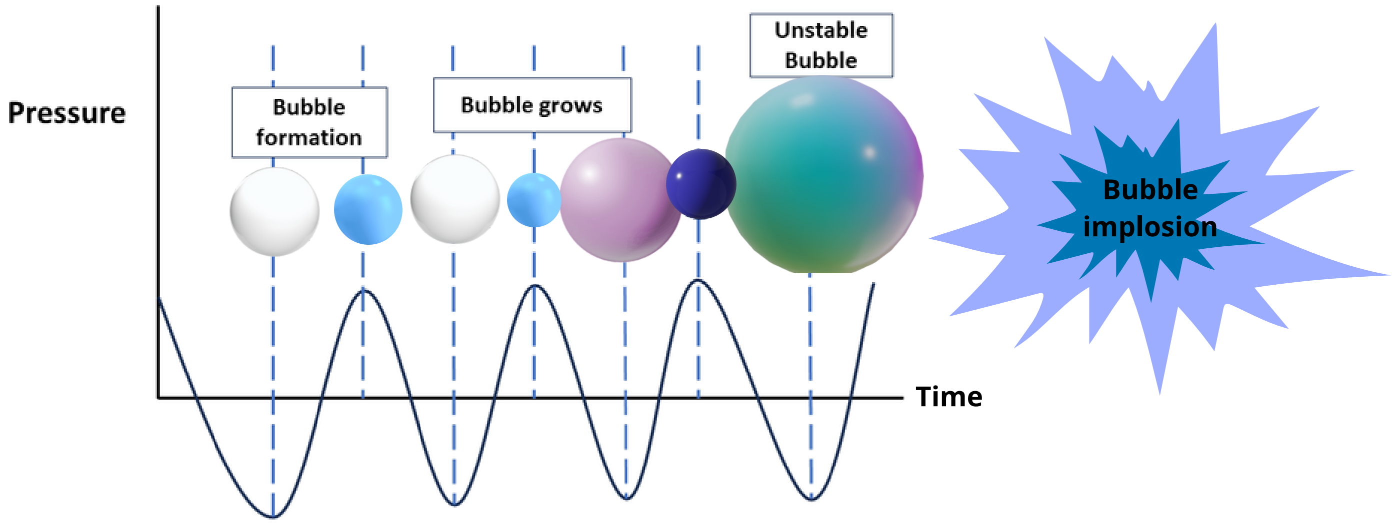
Stainless steel may be a promising electrode material due to its high strength and low cost (Karami, 2022). Additionally, it is important to consider that significant research should be conducted to understand the mechanisms of this method in the environment and its effect on different mass transfer parameters in ISL.

Secondly, the ultrasonic transfer method consists of propagating ultrasonic waves in the medium with the objective of generating intense pressure variations and temperature increases.

On the one hand, the pressure differences increase the penetration of the leaching solution into the porous medium and promote the transport of ions between solid and liquid.

On the other hand, the increase in temperature generates an increase in the solubility of the substances in the leaching solution and an increased diffusivity of the compounds through the medium. These temperature and pressure changes produce a collapse of the cavities in the liquid called bubbles, which generates heat, increased agitation speed and activation of chemical processes, improving mass transfer in the porous medium (**see Figure 4**).

FIGURE 4: PROMOTION OF MASS TRANSFER USING ULTRASOUND



Source: GEM own elaboration

It has been experimentally demonstrated that the ultrasonic method allows increasing the speed of chemical reactions and leaching of copper and other metals. It also contributes to the reduction of the size and, therefore, allows for increased recovery and decreased leaching time. **It is essential to select an appropriate power and frequency to increase the efficiency of the method**. Although many ultrasonic extraction processes have been studied, its application in ISL has only been investigated at a laboratory scale. Limitations for its implementation on an industrial scale include transducer design, heating and noise effects, and high energy consumption.

To save energy and achieve a more economical process, this method could be applied on a pulsed (a few hours per day) rather than continuous basis (Karami, 2022).

The combination of electrokinetic and ultrasonic mass transfer methods could be effective and further increase recovery in ISL. The joint application of these methods has been experimented in the removal of contaminants from the subsurface, reaching a removal rate of about 90% (Karami, 2022). However, it is important to consider the equipment installation costs and the high energy consumption of both methods.

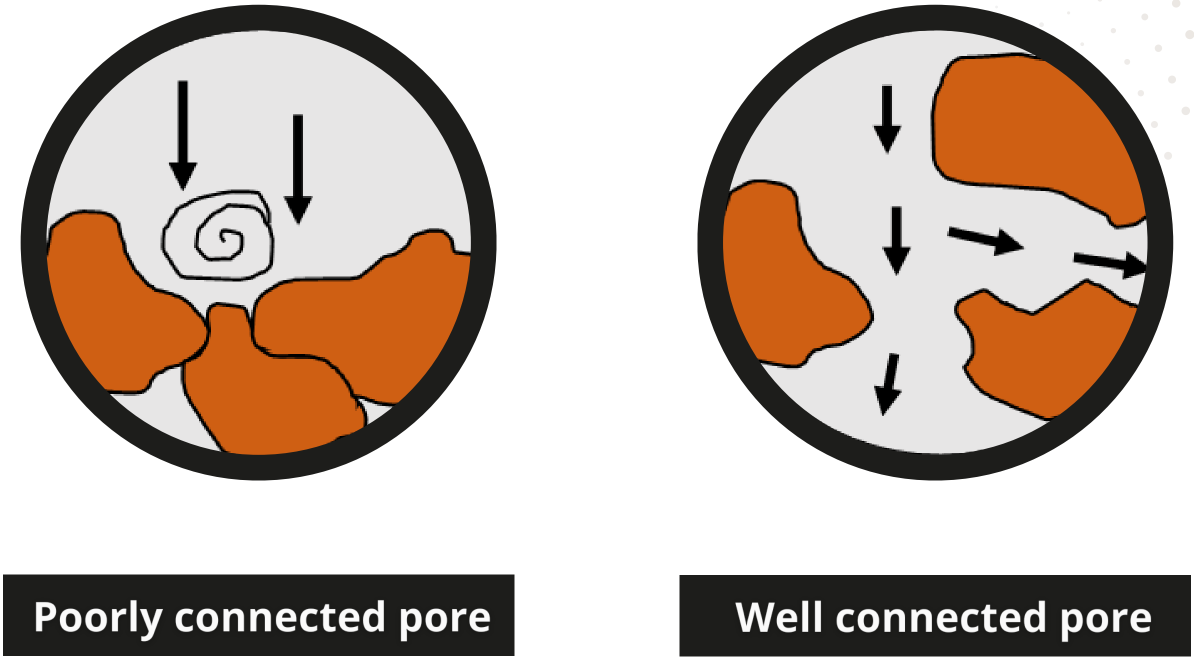
Third, the mass transfer method using solution pulses consists of pumping the liquid into the solid intermittently instead of continuously, in order to generate a slow mass transfer from dead-end pores to well-connected pores or permeable zones. The difference between these two types of pores can be seen in **Figure 5**.

This method has been applied mainly in groundwater decontamination. The system must pump when the concentration of contaminants in the well-connected pores is high.

Once this concentration has decreased significantly, the pump must be turned off. The concentration gradient drives the contaminants from the dead-end pores into the well-connected pores, again increasing the concentration in these zones. In this way, only water containing a high level of contaminants in the permeable zone is removed.

The total pumping time and total volume of water withdrawn can be decreased using this method, resulting in a reduction of the high costs of pumping water through injection wells.

FIGURE 5: PROMOTION OF MASS TRANSFER BY SOLUTION PULSES



Source: GEM own elaboration

Finally, the hydraulic fracturing or fracking method, mainly used in oil extraction, consists of injecting a mixture of water, sand and chemical additives at high pressure into an oil well to create fractures in the subway rock and release the hydrocarbons trapped in it. Once the hydraulic pressure is removed from the well, the fractures are kept open by the injected fluid, which facilitates the extraction of oil and gas from the interior (see **Figure 6**).

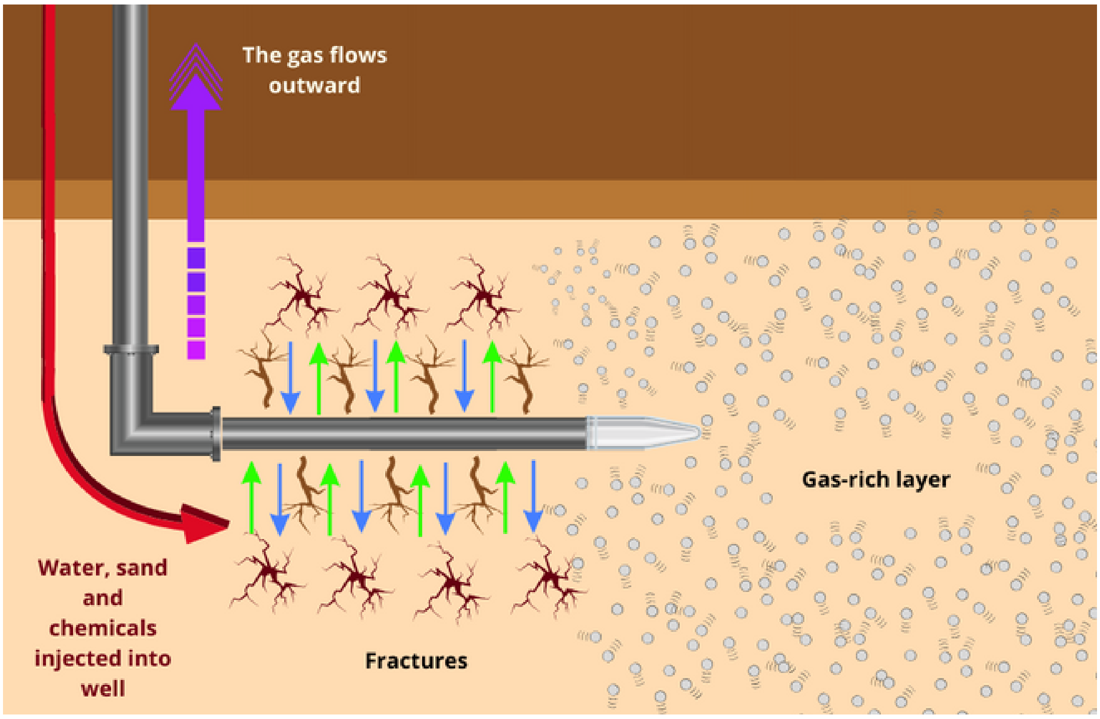
Both natural and artificially induced fractures can be enlarged by fracking. This method allows increasing the recovery rate by increasing the permeability of the reservoir.

Another point to consider is that the wastewater from this process can seep into the surrounding water sources and contaminate the drinking water; to avoid this risk, a mixture without chemical agents could be injected. It should be noted that some studies indicate that this technique could potentially influence the generation of earthquakes.

This method allows increasing the recovery rate by increasing the permeability of the reservoir. One of the limitations of this process is the methane emissions generated, which can have a negative impact on air quality and the environment.

However, in the case of this method is carried out at depths of more than 4,000 meters, which can increase the pressure of subway rocks and the occurrence of landslides. If this technique is applied to near-surface ores, it would not generate enough pressure to trigger landslides on deep geological faults, ruling out the induction of earthquakes.

FIGURE 6: PROMOTION OF MASS TRANSFER BY FRACKING



Source: GEM own elaboration

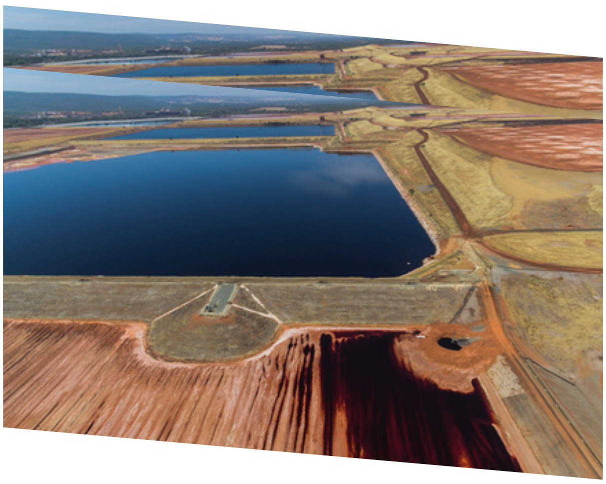
COMPARATIVE ANALYSIS OF ISL

Comparative analysis of ISL enhanced with mass transfer methods with respect to the conventional leaching method.

As noted above, ISL could have many benefits over conventional heap leaching, mainly associated with the potential environmental requirements and long-term sustainability of mining.

However, one of the main constraints to apply ISL is related to the hydraulic conductivity and permeability of the deposit, **which generally leads to lower leaching performance and leaching rate compared to heap leaching.**

However, in recent years, promising complementary methods, explained in the previous section, such as electrokinetic transfer have been discovered that could increase the permeability of the deposit and, therefore, the leaching yield and rate, warranting further investigation of these methods to improve and/or accelerate mineral recovery by ISL.



Other limitations correspond to the risk of leachate seepage and groundwater contamination in the case of non-impermeable lower strata, for this reason it is very important to study in depth the hydrogeological characteristics of the deposit and to build monitoring wells to control the flow.

It is also relevant to consider the high energy costs associated with pumping and complementary mass transfer methods to improve ISL performance.

However, climatic conditions could be taken advantage of to use renewable energy sources. **Figure 7** shows a comparative analysis chart between enhanced ISL with possible mass transfer methods and conventional heap leaching.

FIGURE 7: COMPARATIVE ANALYSIS OF ENHANCED IN-SITU LEACHING VERSUS HEAP LEACHING

Criteria	Enhanced in-situ leaching vs. heap leaching	Comments
Hydrogeological constraints	?	In situ leaching requires hydrogeological conditions of the deposits to be feasible (conductivity and permeability). However, with the adoption of complementary methods, mass transfer and permeability of the deposit could be increased.
Performance	?	Heap leaching generally allows greater contact between the leaching agent and the blast ore. However, the in-situ leaching method enhanced with mass transfer promotion techniques would increase recovery to levels close to those of heap leaching.
Leaching Time	?	Heap leaching generally allows a higher leaching rate due to the higher permeability acquired by crushing the material. However, by supplementing in-situ leaching with methods that could increase the leaching rate, even shorter times than heap leaching could be achieved.
Risk of leachate seepage and groundwater contamination	+	In-situ leaching has a higher risk of leachant losses and contamination of surrounding water bodies due to non-impermeable lower strata.
Leaching costs	+	In situ leaching includes costs associated with injection and recovery pumps and wells, which could involve high energy consumption if complementary methods are also included. While in heaps, leaching occurs by percolation, so the main cost is associated with the surface irrigation system.
Water consumption	−	In situ leaching would have lower water consumption due to: a lower evaporation rate of the leaching agent due to its subway action, decreased formation of flow paths due to less pore fracturing, and increased diffusion of the leaching agent due to the spreading plume injected by wells.
CO_2 Emissions	−	In-situ leaching could reduce CO2 emissions by reducing the use of machinery associated with blasting, transporting and stacking processes.
Visual pollution	−	In-situ leaching does not create heaps or dumps on the surface, thus reducing the use of machinery.
Safe working conditions	+	Leaching heaps more prone to cause accidents or collapse due to height and surface exposure
Applicability in deep and/or low grade deposits	+	In-situ leaching would allow deep, low-grade deposits to be mined cost-effectively due to the use of shafts, saving the high costs of excavation
Ore preparation and stockpiling costs	−	In-situ leaching does not include costs related to blasting, transport and stockpiling processes.
Manpower	−	In-situ leaching requires fewer operators, as the process relies mainly on the operation of injection and recovery wells.

Source: GEM own elaboration

Note: The + or - sign represents that the ISL method shows a higher or lower criterion value with respect to heap leaching, respectively. The sign ? indicates that further investigation is required.

FUTURE OF ISL METHOD

Before making any decisions about potential ISL operations, it is important to evaluate the efficiency and cost-effectiveness of the project from the preliminary study stage through the pilot operation and feasibility engineering stage.

First, companies interested in investigating the potential of ISL in their reservoirs should conduct a conceptual study of the options and risks associated with implementing the method to identify the key variables that determine the process.

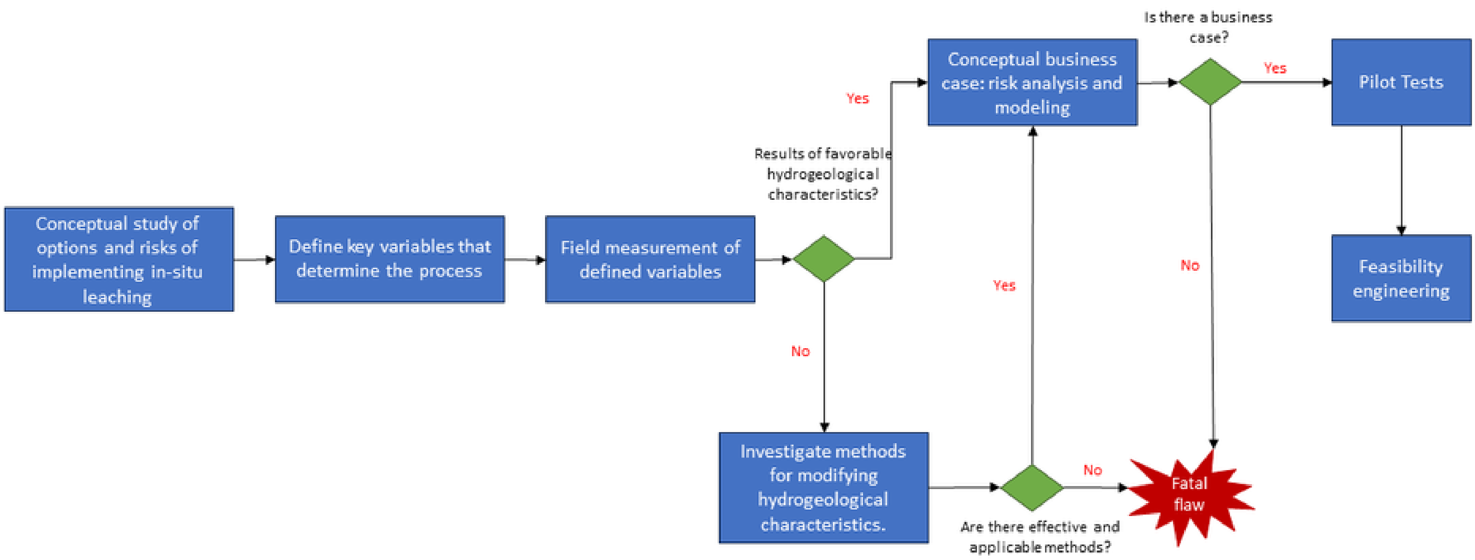
Once the variables have been defined, in situ, measured data should be collected for these variables. If the hydrogeological characteristics of the reservoir are not favorable, e.g., the hydraulic conductivity is very low, techniques to modify these characteristics such as the mass transfer methods presented in this paper would have to be investigated.

Conversely, if the reservoir characteristics are within a reasonable range, a risk analysis and reactive transport modeling should be performed to identify if a business case exists.

Risk analysis is a fundamental tool for determining the feasibility of the project, as it quantifies the uncertainty associated with the business, including variables such as throughput, process costs and market prices.

If there is indeed a business case, the pilot operation and pre-feasibility and feasibility engineering stage would be entered. The diagram in **Figure 8** summarizes the steps proposed to analyze the feasibility of implementing ISL in any given warehouse.

FIGURE 8. FLOW CHART FOR *IN SITU* LEACHING IMPLEMENTATION



Source: GEM own elaboration

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