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The greenhouse gas footprint of in-situ leaching of uranium, gold and copper in Australia

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ABSTRACT

In-situ leaching (ISL) is a chemical method for recovering useful minerals and metals directly from underground ore bodies which is also referred to as 'solution mining'. ISL is commonly used for uranium mining, accounting for about 45% of global production. The main benefits are claimed to be a lower environmental impact in terms of visual disturbances, emissions, lower energy use, cost compared with conventional open-cut or underground mining methods, and potential utilisation of lower grade resources. However, there is a lack of reported studies on the assessment of the environmental impacts of ISL, particularly greenhouse gas (GHG) emissions using life cycle assessment (LCA) methodology. The SimaPro LCA software was used to estimate the GHG footprint of the ISL of uranium, gold and copper. The total GHG emissions were estimated to be 38.0 kg CO_2-e/kg U_3O_8 concentrate (yellowcake), 29 t CO_2-e/kg gold, and 4.78 kg CO_2-e/kg Cu. The GHG footprint of ISL uranium was significantly lower than that of conventional mining, however, the footprints of copper and gold were not much less compared with conventional mining methods. This is due to the lower ore grade of ISL deposits and recovery compared with high ore grades and recovery of conventional technology. Additionally, the use of large amount of electricity for pumping in case of ISL contributes to this result. The electricity consumed in pumping leaching solutions was by far the greatest contributor to the well-field related activities associated with ISL of uranium, gold and copper. The main strategy to reduce the GHG footprint of ISL mining should be to use electricity derived from low emission sources. In particular, renewable sources such as solar would be suitable for ISL as these operations are typically in remote locations with smaller deposits compared with conventional mining sites.

1. Introduction

In-situ leaching (ISL) has become a common mining method with relatively low visible impact compared with open-pit surface mining. ISL is basically a chemical method of recovering useful minerals and metals directly from underground ore bodies. This mining method is often classified under solution mining that includes all forms of extraction of materials from the earth by leaching and fluid recovery (Canterford, 1983; Barlett, 1992). The various forms of solution mining are ISL, heap leaching and dump leaching. The metallic ore minerals require leaching reactions with acids or other chemical lixiviants and also oxidation of the minerals for metal extraction. A lixiviant is a liquid medium used to selectively extract the desired metal from the ore or mineral and assists in achieving rapid and complete leaching. The metal can be recovered from it in a concentrated form after leaching. A lixiviant solution may be acidic or basic in nature. If calcium is present in ore-body, carbonate alkaline leaching is often preferred, otherwise acid is mostly used.

In-situ leaching generally involves extraction of minerals or metals from the undisturbed ore in place. The extraction operation is often coupled with a mineral recovery operation, generally on the surface adjacent to the extraction process where the dissolved metals or minerals are separated from the recovered fluid solution or leachate. A large volume of solution circulates between the extraction and recovery operations, with both gravity flow and pumping used to transport the leaching solutions. Leachates generated by the extraction operation are termed as "pregnant solutions" and the fluids returned to the extraction operation are referred to "barren solutions". Permeability of the ore-body is a key factor in ISL as it relies on open void space or natural fractures in the ore for solution flow paths. This permeability may be artificially increased with controlled blasting by fragmenting of ores in place, called "rubblizing". Hydrological aspects of groundwater

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composition, flow and recharge, are important in terms of the effectiveness of the leach lixiviant injection and extraction.

For ISL mining to be feasible, the deposit must possess certain properties, namely, the deposit must be in an aquifer, the aquifer sediments must be permeable, and the sediments must be vertically confined above and below the impermeable layers. The operation of an ISL mine involves the management and optimisation of two distinct processes:

- well-field extraction of the mineral or metal from the deposit;
- recovery of this extracted mineral or metal from the lixiviant and production of a suitable product (eg. concentrate or metal) for shipment.

There are several claimed advantages of ISL mining over conventional mining methods, in particular, lower surface disturbances and capital cost because of less usage of energy-intensive mobile equipment (i.e. loading, hauling and dumping (LHD) vehicles) and comminution (crushing and grinding) circuits.

There are many deep lead or palaeo-channel gold, copper, nickel and uranium deposits in Australia that might be suitable for ISL, particularly in southern Australia for gold and uranium (Johns and Parr, 2010). However, techno-economic and environmental evaluations will be critical if these deposits are to be successfully exploited. There are no studies reported in the literature on the greenhouse gas (GHG) footprint of ISL using life cycle assessment (LCA) methodology, which the study described in this paper seeks to address. Water footprint, toxicity and leakage of solutions are important environmental factors for deciding ISL mining operations. Since this paper focuses on GHG, other relevant factors have been considered out of the scope of present study. The research is underway for a future paper on the assessment of other important factors except GHG.

1.1. Uranium

In the case of ISL of uranium, the ISL involves the extraction of uranium from the host sandstone by chemical solutions followed by recovery of uranium at the surface. The ISL extraction is conducted by injecting a suitable lixiviant into the ore zone below the water table, oxidizing, complexing, and mobilizing the uranium, and recovering the pregnant solution through production wells. Finally, the uranium bearing solution is pumped to the surface for further processing (IAEA, 2001).

Extraction by ISL mining is the primary uranium extraction process in the US, with about 90% of US uranium extracted by this method (Mudd, 2001). Uranium extraction in Kazakhstan is almost entirely by ISL and supplies about 28% of the world supply (Kazatomprom, 2012). In 2009, a total of 18,262 t uranium was produced by ISL in the world, with 13,473 t in Kazakhstan, 2429 t in Uzbekistan, 1217 t in USA, 583 t in Australia and 560 t in Russia. This was 45% of world total production, a share which has risen steadily from 16% in 2000 (WNA website, 2013).

There are two uranium ISL mines operating commercially in Australia which contribute about 9% to total Australian uranium production (IBIS Industry Report, 2011). The Beverley uranium deposit in South Australia started commercial operation through the ownership of Heathgate Resources Pty Ltd, a wholly-owned Australian subsidiary of US-based General Atomics Corporation in 2001. The uranium mineralisation occurs within semi-isolated aquifer sands that resemble a concealed fluvial system or palaeo-channel (Mudd, 2001). The Beverley mine has a licence to produce 1,500 t/y of uranium oxide equivalent, although the production has been less than this for most years. The output was 630 tonnes in both 2008–09 and 2009–10, and in 2010–11 the production fell to 347 tonnes due to disruption caused by extremely wet weather (IBIS Industry Report, 2011).

The Honeymoon ISL project in South Australia (Absolon et al., 2006) commenced production in 2011 with a licence to produce 400 t/y. The Honeymoon project is owned by Southern Cross Resources Australia Pty Ltd with joint ownership by Uranium One Inc, a Canadian-based company and Japanese Mitsui & Co Ltd. The reported production in 2011 was 227 tonnes (SEDAR, 2012). The Beverley and Honeymoon uranium deposits are located in the arid Lake Frome region of South Australia. The LCA of uranium ISL mining described in this paper used inventory data reported for both the Beverley and Honeymoon operations.

1.2. Gold

There are several technical challenges to be overcome for successful ISL mining of gold. One is to find an environmentally benign lixiviant-oxidant solution for gold beneficiation. Thiosulphate has recently been investigated by CSIRO for this purpose. Another challenge is to improve the permeability of gold oxide ores. These ores are less permeable than the ore deposits in typical uranium ISL operations, meaning that without artificial permeability enhancement, gold ISL extraction rates are likely to be too low for the process to be economically viable. Yet a further challenge is to improve the efficiency of production. This can be accomplished either by increasing the recovery of minerals in the pregnant leach liquor by optimising the design of the well-field (with the same number of wells), or by reducing the number of wells with the same recovery of minerals. Either approach will reduce the cost of operation per unit of product. In the former case, this cost reduction results from the increased production per well, or in the latter case results from fewer wells and lower associated drilling and pumping costs.

A gold deposit suitable for ISL should ideally be an oxide deposit. If it is a sulphide deposit, then a preceding step of oxidation using ferric ions should be undertaken to oxidise the sulphides before ISL, resulting in additional cost and complexity. CSIRO has studied the use of bio-organisms to oxidise sulphides to make them amenable to ISL both conceptually and in the laboratory. The concept uses a bioreactor above ground together with a bio-mining approach in the underground ore-body. This gold extraction process would appear to be quite complex and requires further extensive study before any commercialisation is considered. There are no known commercial applications of ISL of gold using cyanide. In the 1980s, ISL using thiosulphate was tested underground in the Witwatersrand in South Africa, but no commercial application emerged from this work (Marsden and House, 2006). For the sake of this study, an LCA of a conceptual gold ISL process was carried out to provide preliminary results for comparative purposes.

1.3. Copper

ISL mining has also been applied to copper ore deposits. CSIRO was involved with trials of solution mining of copper at the Mutooroo deposit in South Australia (Canterford, 1983). Excelsior Mining Corporation has recently published an independent technical report in relation to their Gunnison copper ISL project which is located in the Arizona copper belt, USA (Independent Mining Consultants, 2011; Huss et al., 2011). This deposit has 1.4 Mt of indicated and 0.4 Mt of inferred Cu in the form of oxide ores at 0.1% grade. Both of these reports provide the justification for ISL mining over conventional mining for this particular deposit. Although this project is at an early stage of development, there is enough information regarding chemical requirements and conceptual operational data in these reports to conduct a first-pass LCA of this

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