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ECONOMIC MODELLING OF KAPUNDA ISR COPPER MINE PROJECT

by:

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Declaration

I, Hetal Mohan Bhatia, confirm that the work presented in this thesis is my own.

Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

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Table of Contents

Abstract:

This paper demonstrates the economic viability of implementing in-situ recovery (ISR) mining technique for a low-grade copper deposit. In the face of challenging economics in mining, the miners must seek inventive approaches for mineral extraction, particularly for copper, given the anticipated long-term deficit in global markets. Australia's geology and hydrology offer a favorable setting for ISR to expand beyond uranium to critical minerals such as copper. This study provides a comprehensive techno-economic analysis of the Kapunda ISR copper mine project in South Australia, with support from EnviroCopper (ECR), the company leading the exploration activities at the mine site. To evaluate the economic viability, a life of mine (LOM) model was created using the discounted cash flow (DCF) method. This study goes beyond the traditional DCF analysis by conducting a Monte Carlo simulation to address uncertainties, including copper, energy, and consumable market prices. This approach evaluates the project's resilience to unpredictable market trends. The investment appraisal of the project yields a net present value of A$127 million and an (after tax) internal rate of return (IRR) of 42%. With a high return on investment and swift recoupment of the initial investment of A$38 million within 1-3 years, the Kapunda ISR copper mine project emerges as a compelling and economically viable contender to advance for a mining proposal.

Introduction:

Concurrence of declining ore grades and soaring future metals demand driven by the green energy transition is set to provide impetus to innovation in mineral extraction, especially for copper. Copper is an indispensable metal in achieving the net zero emissions target by 2050 under the Paris Accord, as it is essential for building renewable energy technologies such as wind turbines and solar panels, electric vehicle batteries, and power distribution systems. Global copper demand is expected to double to 53 million tonnes/annum by 2050 relative to 2022 (S&P Global, 2022).

The copper mining industry is grappling with two significant challenges: 1. declining ore grades and 2. fewer discoveries of economically viable new mines. Ore grades, production, and energy consumption are strongly correlated and influence the operational efficiency of a mine (Calvo, 2016). For example, between 2003 and 2013, the average Cu ore grades at Chilean mines, the largest copper mining country, declined by 35% to 0.71% Cu in 2013 (Fig. 1a), and the energy consumption increased by 12% to 6,400 kWh/t Cu in 2013 (Fig. 1b) (Calvo, 2016; Cantallopts, 2017). As of 2021, an open pit mine and processing unit consumes about 7,200 kWh/t Cu of energy to process one tonne of 0.5% Cu ore grade (Engeco, 2021). The subsequent effect is increased cost per unit of copper extracted,

squeezing the profitability amid diminishing quality of ore reserves. However, declining copper ore grade quality and robust demand from the green energy transition have propelled miners to seek innovative extraction technologies to decrease the cost of metal recovery.

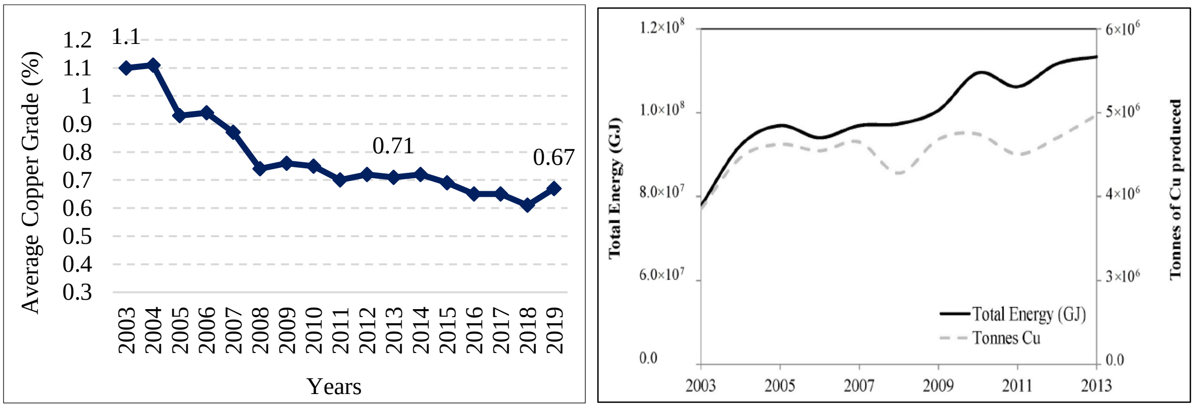

***Figure 1a)**. (Left) Average grade trend for copper mines in Chile. Sourced from International Energy Agency and Cantallopts (2017); **b)** (Right) Total energy (GJ) versus tonnes of copper produced for all the Chilean mines. Taken from Calvo (2016).*

In-situ recovery (ISR) is a promising technique that addresses the cost concerns of depleting ore grade reserves but needs renewed focus and attention. ISR relies on chemical processes to dissolve and extract the minerals underground without physically removing the ore. One of the earliest and most successful proofs of ISR was in uranium. Uranium mines using ISR technology have validated that the capital expenditure (Capex) is significantly lower than conventional mining (Maxim Seredkin, 2016). For example, the capex cost of the ISR Honeymoon uranium mine is a quarter of the conventional (underground) Olympic Dam uranium mine (Maxim Seredkin, 2016). Furthermore, the cash cost for Honeymoon is approximately 25% lower than Olympic Dam. (Maxim Seredkin, 2016; Boss Energy Ltd, 2021). ISR mines also enjoy production flexibility during low commodity prices (Maxim Seredkin, 2016). Numerous ISR projects are underway globally, including in Australia. Kapunda Copper-Gold mine in South Australia is in the advanced stages of applying for an ISR mining license. South Australia also houses Australia's first-ever ISR mine – Beverley uranium mine. Building on the uranium experience, ISR was introduced to copper and gold mines 40 years ago (Maxim Seredkin, 2016). Worldwide, the Florence Copper Project and Gunnison Copper Project in Arizona, USA, are the most recognized ISR copper mine projects. While the economic feasibility is well-established for ISR uranium mines in Australia, there are no comprehensive studies on ISR copper mines.

This dissertation assesses the economic viability of the proposed Kapunda Copper ISR project in South Australia by assessing (a) the copper extraction efficiency, (b) financial feasibility through a life-of-mine model, (c) investment appraisal of the project, and (d) comparing costs with Florence and Gunnison ISR projects in the USA. The investment appraisal analysis includes net present value (NPV) assessment to determine profitability, internal rate of return (IRR) calculation to assess return on investment, and payback period estimation – the number of years to recoup the initial investment, in this case, investment to manufacture copper cathode.

Background:

2.1 In-Situ Recovery

ISR, also popularly known as in-situ leaching, is an “in-place” mineral extraction process with minimal surface disruption that uses a leaching solution to extract metal from the ore deposits near or beneath the surface (Glenn O’Gorman, 2004). ISR is a cost-effective technique that tackles the issue of mineral extraction from low-grade ore deposits and offers environmental benefits. ISR benefits, compared to conventional mining, include (a) a significant reduction in environmental footprint – no use of explosives to blast mineral-hosted deposits, no diesel-based truck needed for ore transportation, lower strip ratio, and promotes sustainable mining. (b) requires less energy – eliminates the comminution process, and thereby lowers costs. Comminution consumes 30-35% of total energy in copper mining (Engeco, 2021). (c) most importantly, ISR thrives on low-grade ore deposits and is suitable for fragmented small-medium-sized deposits. However, the geology and hydrology of mineral-hosted deposits are pivotal for ISR's success (Calvo, 2016).

The ore deposit may host mixed oxide and/or sulfide ores. The mineral extraction process is similar to oil and gas extraction, a wellfield - network of bore wells (injection, extraction, monitoring wells) is constructed (Fig. 2a). A leaching solution or lixiviant, which is a reactive fluid, is injected into the wells and flows through the permeable and porous geological substrate. The most common lixiviant used for ISR mining is sulfuric acid due to abundant availability and low cost; however, its reaction in the presence of pyrite, water, air, and micro-organisms in sulfide deposits may lead to soil and water contamination (Glenn O’Gorman, 2004).

The biggest hurdle in the scalability of ISR technology is the permeability of the mineral-hosted deposit, as a permeable host rock is required to allow the lixiviant solution to flow easily through its pores or spaces and extract metal into the leaching solution (Glenn O’Gorman, 2004; Mudd, 2002). ISR mining faces additional challenges associated with low metal recovery rates. The copper recovery rate at the San Manuel mine, after it transitioned to ISR mining in 1986, ranged between 50%-60% over a five-year period (Glenn O’Gorman, 2004). To improve the metal recovery from the ore deposit, the leaching solution may contain oxidants such as oxygen gas, hydrogen peroxide, nitric acid, or ferric chloride (Glenn O'Gorman, 2004).

The leaching solution with the dissolved copper is called pregnant leaching solution (PLS). The PLS is pumped through the extraction wells to the surface and processed. The PLS, along with the desirable metal, also contains other metals present in the ore deposits. Hence, common separation/processing techniques such as solvent extraction (SX) or ion exchange (IX) isolate the desired metal from the solution to produce concentrated ores (Fig. 2b) (Glenn O'Gorman, 2004). The concentrated ore then goes for electrowinning (EW), a refining process to obtain high-purity metal, in this case, copper cathode with 99.99% Cu purity.

The waste from the processing plant is deposited in a pond to precipitate the excess moisture and solidify it for easy waste disposal. Additionally, in mining, depending on the type of lixiviant, it can be recycled and reused in addition to fresh lixiviant, in some cases, the recycling rate of sulfuric acid is as high as 90% (Wall, 2021).

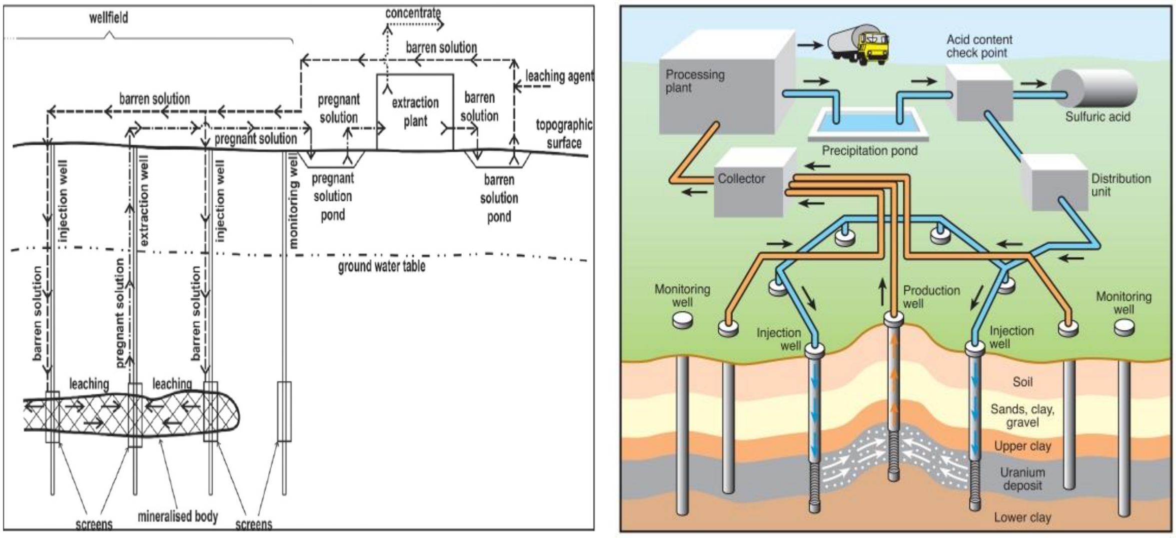

***Figure 2a)**. (Left) A conceptual ISR mine. Taken from Maxim Seredkin (2016); **b)** (Right) ISR mine and processing chart. Taken from Carla M. Zammit (2014)*

2.2 Kapunda Mine Site

Located 150 kilometres north of Adelaide, Kapunda is the oldest mining town in Australia. Copper mining in Kapunda began in 1849, after its discovery in 1842, and continued until 1878-79, after which the fall in copper prices made mining uneconomical. The mine site is in the town area, with a population of 2,947 as of 2021 (Australian Bureau of Statistics, 2021). The Light River, originating from the northern slopes of the Mount Lofty Ranges, flows through Kapunda towards the south, passing through several localities. Many companies carried out exploration activities between 1965 and 2008. EnviroCopper (ECR), established in 2017 to tap into the potential of ISR mining in Australia, has received government grants and corporate investments to carry out exploration tests at the Kapunda ISR mine site. The copper resource is estimated at 119,000 tons at a grade range between 0.18% and 0.23% (ECR, 2021). Kapunda's annual copper cathode production estimate stands at ~4,500t. The depth of mineralization is between 40 and 250m below the surface (ECR, 2021). Initially an open pit mine, Kapunda mine transitioned into an underground mine with a depth of 120 m below the surface, and the deposits host both copper oxide and sulfide ores (Hang Wang, 2022).

2.3 Kapunda Geology and Hydrology

The Kapunda mine is proposed to have formed between 490 and 510 million years ago during the Neoproterozoic to early Cambrian geological period (Bamforth, 2019). Initial rifting led to the formation of the Adelaide super basin. The subsequent deformation led to the development of faults, which acted as a path for metal-laden fluids that were associated with mineralisation (Maxim Seredkin, 2016). Resultant copper mineralisation is now hosted in a stratiform deposit of dolosiltstones within a sequence of dark-coloured, fine-grained mudstones and siltstone and is concentrated within veins (Hang Wang, 2022). The mineralization comprises chalcopyrite, pyrite, pyrrhotite, carbonate, and quartz (Maxim Seredkin, 2016). The gangue minerals found in the samples include biotite, K-jarosite, gypsum, pyrite, goethite, barite, calcite, and halite, mostly below 2% concentration (Maxim Seredkin, 2016).

The groundwater level at Kapunda is ~20 m below the surface (SARIG). The groundwater flow rate is extremely slow at 50 cm a year. The groundwater is highly saline at 3000–7000 ppm and is unsuitable for drinking or agricultural usage (SARIG). The copper concentration in the groundwater is 300–400 ppm (MET, 2016). The ore body is connected through two aquifers; the top layer is relatively saturated and is an unconfined aquifer (free water table) and is connected to the fully saturated bottom layer through porous dolosiltstone strata (Hang Wang, 2022). The unconfined aquifer may contribute to a geochemical reaction in the presence of pyrite and, therefore, may be a possible threat to water contamination. Historical records show that the underground mine encountered (ground) water influx, resulting in operational difficulties resolved by pumping water out of the mine (MET, 2016).

2.4 Other ISR Projects

Gunnison and Florence, leading global ISR copper mine projects located in Arizona, USA, are owned by Excelsior Mining Corporation and Taseko Mines Limited, respectively (Richard

Tremblay, 2023; Richard Zimmerman, 2022). The projects serve as benchmarks for cost comparative analysis with the Kapunda ISR copper mine project because of their similar geology and hydrological characteristics. A critical technology difference to Kapunda is that both projects use solvent extraction (SX) technology to extract copper (Richard Tremblay, 2023; Richard Zimmerman, 2022). Additionally, the Honeymoon ISR uranium mine project in New South Wales, Australia, owned by Boss Energy Limited, plans to transition to IX technology, as proposed for Kapunda (Boss Energy Ltd, 2021).

Taseko commenced construction of the Florence ISR copper mine in early 2021. Excelsior commissioned phase one of the three phases of the Gunnison ISR copper mine project in December 2020 to produce 11,300t/yr of copper cathode (Richard Zimmerman, 2022).

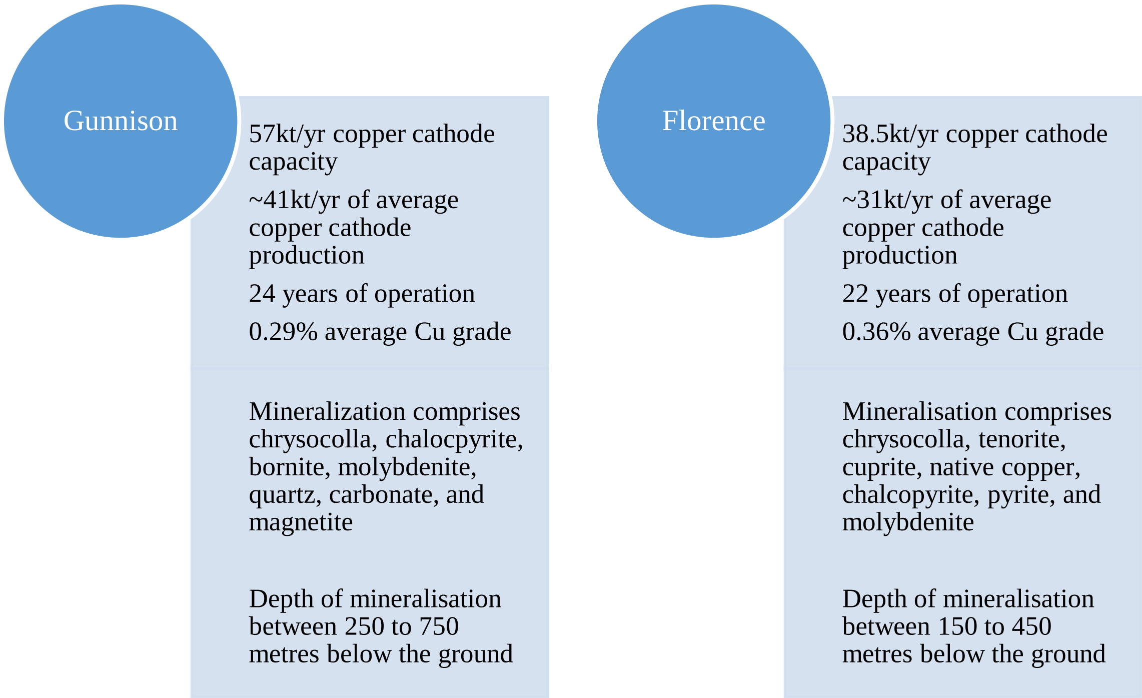

Figure 3. *Gunnison and Florence ISR copper mine overview. Sourced from Richard Zimmerman (2022) and Richard Tremblay (2023)*

Honeymoon Uranium Mine commenced operations in 2011 and is Australia's second operational ISR mine (Boss Energy Ltd, 2021). The plant producing yellow cake (U_3O_8) was placed in care and maintenance in 2014 due to low uranium prices (Boss Energy Ltd, 2021). Boss Energy Limited acquired the Honeymoon uranium mine in December 2015, intending to improve project economics by expansion and cost optimization via technology improvements – to switch from SX to IX technology (Boss Energy Ltd, 2021).

Methodology

The economic assessment of the Kapunda ISR copper mine is pivotal in securing funding and government approvals for full-scale operations. The assessment comprises three main components: 1. evaluating the potential for copper cathode production; 2. developing a detailed LOM model; and 3. performing investment appraisal analysis using risk assessment tools. Investment appraisal is a crucial assessment tool for making informed decisions regarding the project's advancement, as it establishes financial merit. The assessment includes determining project profitability by conducting an NPV analysis basis, evaluating the project return on investment by calculating the internal rate of return (IRR), and estimating the payback period (timeframe to recover the initial investments). The study strengthens the project's investment appraisal assessment by conducting sensitivity analysis and running Monte Carlo simulations, which assess the uncertain variables across multiple scenarios to assign probabilities to the outcome, in this case, NPV.

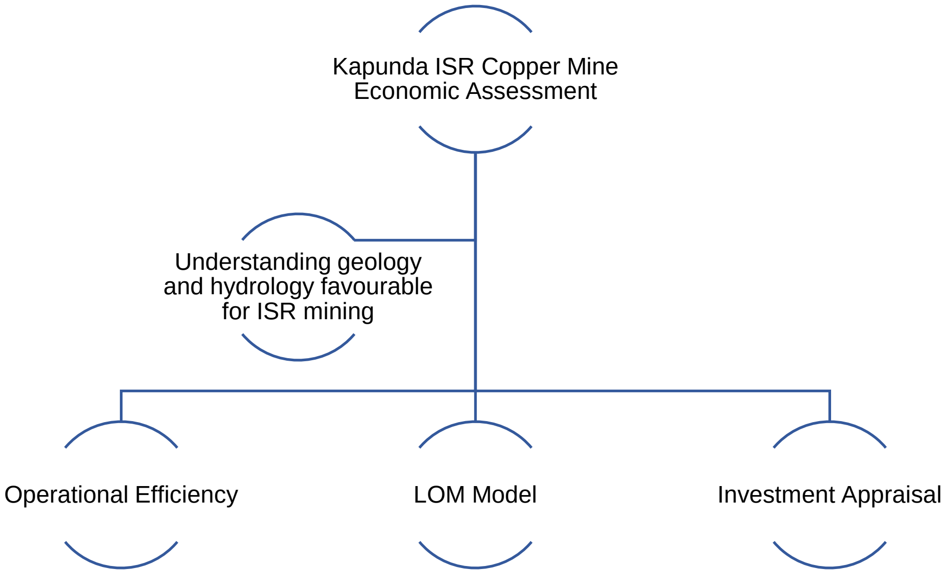

Figure 4. *Key components for economic assessment of Kapunda ISR copper mine project*

3.1 Estimating Copper Production at Kapunda

Evaluating the copper extraction capability of the mine and thereby estimating the probable annual copper cathode production forms the basis for developing a LOM model. Technical information was collated from ECR comprehensive lab and field test reports, including but not limited to well count, well flow rate, PLS flow rate, raffinate specification, PLS specification, and preferred technology (IX). Leveraging the technical information, (a) a process flow chart was formulated to estimate enriched electrolyte (copper mass transferred) to the electrowinning (EW) process stage (Fig 5). The calculation establishes the potential for copper cathode production in a year and concurs with ECR's estimates. A key challenge in the estimation was the absence of trial data of copper (residue) mass (post EW process) contained in a depleted electrolyte solution, which is often re-processed (Fig 5). The depleted electrolyte is assumed as a percentage of enriched electrolyte based on the Gunnison ISR copper mine project to complete the process flow for Kapunda.

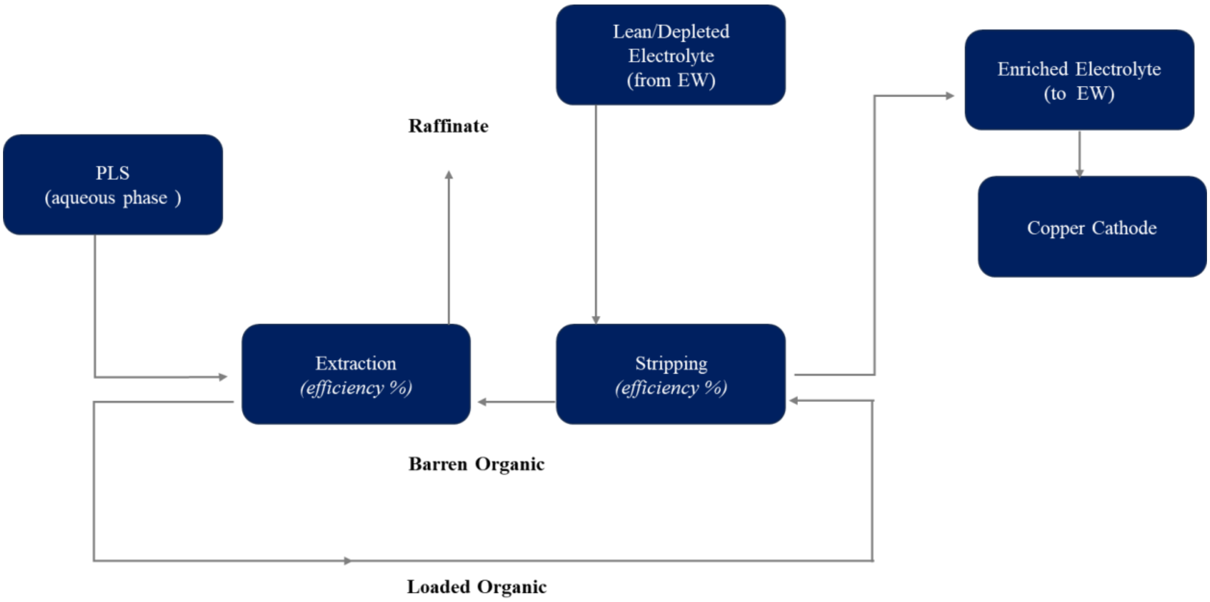

Figure 5. *Process flow chart for copper extraction. Sourced from Maxim Seredkin (2016), Glenn O'Gorman (2004), Hang Wang (2022)*

3.2 Approach to Develop a Life of Mine Model

A detailed LOM model was developed to estimate the profit potential of the Kapunda ISR copper mining project, building on the copper production over the mine life. ECR has indicated that the mine is proposed to commence operations in 2026 and will operate 24/7 for 355 days a year for 18 years. The LOM model covers parameters across the value chain from ore to cathode. The model includes (a) operational efficiency, (b) revenue projections, (c) Capex and Opex costs, and (d) royalty and corporate tax to determine project profitability (Fig 6). The LOM model's accuracy ranges from - 30% to +30%. The quantity estimated for annual cathode production and the market price for copper cathode with 99.99% copper purity, as registered on the London Metal Exchange (LME), forms the basis for annual revenue projections.

The capex costs were based on analysis referencing the Gunnison and Florence ISR copper mine projects and the Honeymoon ISR uranium mine project. Purchase power parity, published by the Organisation for Economic Co-operation and Development (OCED), is a macroeconomic metric used to equalise purchase costs between Gunnison and Florence in the USA and Kapunda in Australia.

Opex costs, including energy, consumables, and employees, were derived based on the per-unit consumption requirement and the cost to the company for each component. Consumables are a key cost component in the ISR mining technique, constituting at least

50% of the opex costs (Richard Zimmerman, 2022; Richard Tremblay, 2023). The consumables – lixiviants and oxidants preferred by ECR, used for ISR mining are methanesulfonic acid (MSA), ferric chloride, and sulfuric acid (Clausen, 2023). The quantity of the consumables required for extracting one tonne of copper was derived based on their chemical reaction with copper oxide (target ore body), and the consumption estimate for MSA falls in the range provided by ECR. Specific consumption estimates for these consumables are vital to calculate the consumables costs. Appendix D illustrates chemical reaction that quantifies specific consumption of consumables. Other costs, including chelating resin and other consumables, repairs and maintenance, and other costs, including but not limited to transportation, administrative, and legal fees, were based on general assumptions as a percentage of revenue.

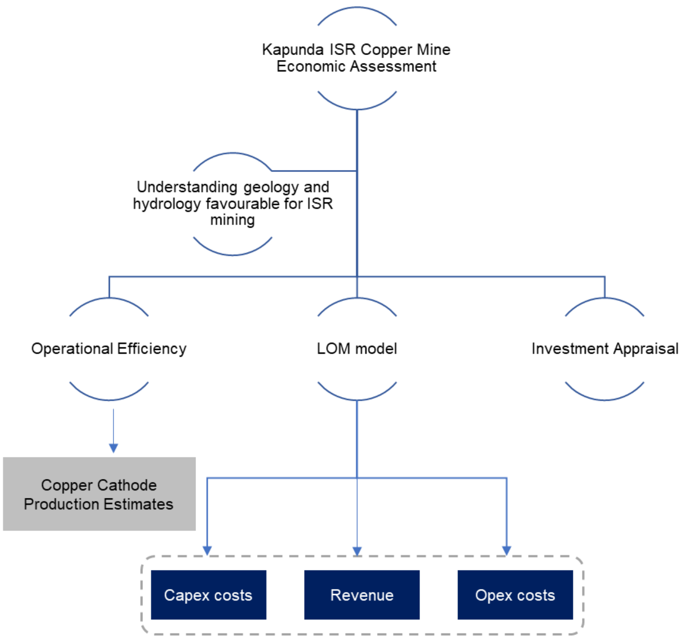

Figure 6. *The critical parameters to create a LOM model*

Table 1 summarizes the information sources and assumptions to develop Kapunda's LOM model. In-depth details are provided in Appendix A. The study also conducts per ton basis peer analysis to benchmark Kapunda's capex and opex costs amongst prominent ISR copper mine projects. The Gunnison and Florence ISR copper projects were selected based on the project stage (advanced/operational), accessibility, and availability of information.

***Table 1**. Information Sources for Kapunda's LOM model*

	Information modelled	**Sources/Assumption**
Operational Efficiency	PLS flow rate and specification, groundwater flow rate, lixiviant and oxidant choice, copper extraction technology	ECR, Hang Wang (2022), Glenn O'Gorman (2004), Bamforth (2019).

Revenue	Copper cathode production and capacity estimate	Independent calculations and ECR
	Copper metal price	LME Copper Cash Official (99.9% Cu purity)
	Price inflation	Fastmarket, a price reporting agency, publishes monthly LME copper price
Capex costs	Wellfield, EW, tank farm, and pond costs, site infrastructure, sustaining capital	Gunnison technical pre-feasibility report (Richard Zimmerman, 2022) and Florence ISR copper technical feasibility report (Richard Tremblay, 2023), and ECR
	IX technology cost	Honeymoon Uranium – Updated Feasibility Report (Boss Energy Ltd, 2021)
Opex costs	Lixiviant and oxidant details, manpower estimation, energy requirement	ECR and (Richard Tremblay, 2023)
	Consumables and power prices	ECR
	Annual salary estimation	ECR and Australian Bureau of Statistics
	Royalty and Taxes	Department of Industry, Science and Resources, Australia, and Australian Taxation Office

3.3 General Practice for Investment Appraisal

NPV, IRR, and payback period calculations are popular industry matrices for project economic valuation. A safeguard in investment appraisal is to conduct sensitivity analysis – analysing pessimistic and optimistic scenarios to account for uncertain variables impacting the outcome, NPV.

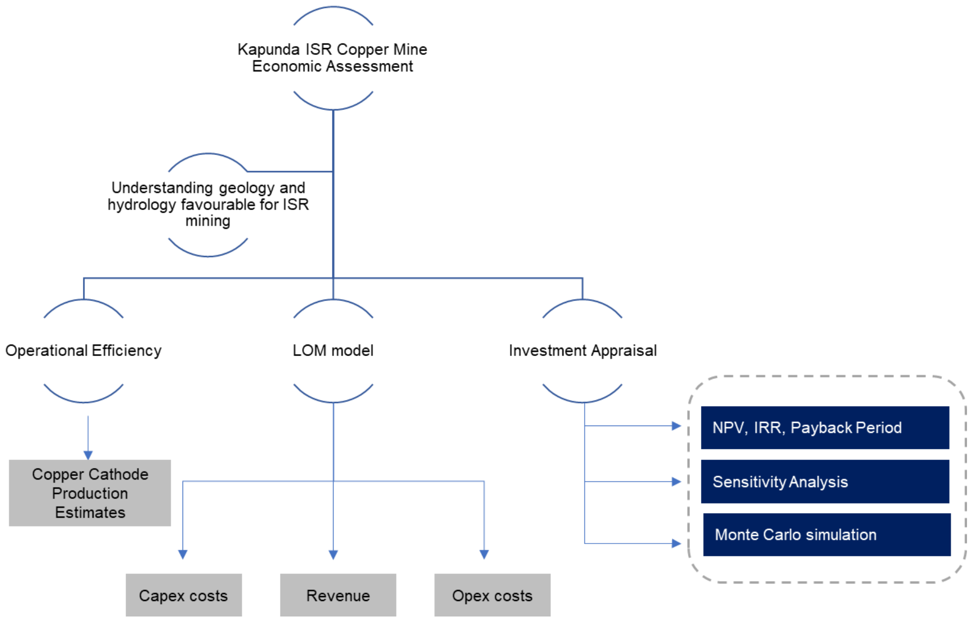

Figure 7*. Investment appraisal parameters and risk assessment tools to establish project economic viability*

NPV evaluation entails a discounted cash flow (DCF) approach based on the LOM excel-based modelling. Amongst various modelling approaches, DCF is the most detailed, thorough, and, hence, preferred. The total cash flows, including the initial investment, are discounted at a rate to arrive at the project's value today (Fig. 8). In this case, the discount rate is the interest rate on borrowing funds.

$$\text{NPV} = -c_0 + \boldsymbol{a}^T \boldsymbol{x}$$

where,
c_0 is initial investment value

i is discount rate,

n is period of the project exploitation

a_j: is net cash flow of the j-th year of the period of project exploitation which occurs at the end of j-th period.

$$x_j = \left(\frac{1}{1+i}\right)^j.$$

Figure 8. NPV Formula. Taken from Latif (2011)

A sensitivity analysis is often presented as a spider graph, showing NPV response to fluctuations in uncertain variables, in this case, copper price, consumables price, energy price, utilization rate, and changes in royalty rate. The study examines optimistic and pessimistic scenarios, evaluating -20% to +20% variations in uncertain variables from the baseline scenario. The goal is to state the impact of the variables on project outcome NPV and rank variables sensitive to NPV, from most to least impactful, depicted using a tornado chart.

Monte Carlo simulation, a sophisticated approach to expand on sensitivity analysis, assigns probabilities to project outcome, NPV. The simulation runs multiple scenarios, factoring randomness in uncertain variables. The simulation model is based on probability distributions such as normal, triangular, binomial, and uniform. The triangular probability distribution is appropriate when the variables lie between a minimum and maximum range along with a most likely scenario, hence preferred for this study. The input variables from the LOM model are the most likely scenario, and the pessimistic and optimistic scenarios provide the minimum and maximum values, respectively. Monte Carlo simulation performed using SimVoi ® is a Microsoft Excel add-in.

Results

The Kapunda ISR copper mine project's average annual revenue is projected at ~A$67 million (M), while the projected yearly Opex costs range between A$30M and A$40M. The average copper cathode production is projected at 4,500t/yr over the 18 years of mine life, with a capacity of 5,300t/yr. The estimated Capex stands at ~A$38M. The LOM model analysis for the Kapunda ISR copper mine project effectively demonstrates economic viability, with an NPV (after tax) of A$127M in the baseline scenario and a payback period of 1 to 3 years. A positive NPV suggests that the project will generate value for the investors and should be approved (Damodaran, n.d.).

4.1 Kapunda's Operational Efficiency

4.1.1 Wellfield to PLS: Operational Insights and Choice of Lixiviant

ECR estimates show Kapunda will require 15-20 operational wells over its mine life, each with a flow rate ranging between 6 and 10 litres per second. The anticipated average PLS flow rate is 550 m3/hr, with an average copper concentration of 1200 mg/l (Wall, 2021). The LOM model assumes 29 wells, including 19 operational wells, verified independently based on well and PLS flow rates. The model assumes an additional ten wells for monitoring purposes and contingencies.

Due to the prevailing acidic (pH less than 7) groundwater conditions at the Kapunda mine site, Methanesulfonic acid (MSA) is one of the preferred lixiviants (ECR, 2021; Clausen, 2023). Using MSA, the average copper recovery rate is 72.5% for copper oxide ores and 68.3% for sulfide ores (ECR, 2021). ECR's leach tests show significant improvement in copper recovery with the addition of an oxidant for sulfide ores (ECR, 2021). Ferric Chloride is the chosen oxidant to target sulfide ores at Kapunda.

4.1.2 Copper Cathode Production Estimation

At a flow rate of 550 m3/hr and copper concentration of 1.2 kg/m3, the PLS carries 660 kg Cu/hr (Wall, 2021). PLS mixed with an organic solvent transfers copper from the PLS to the organic solvent, which becomes loaded organic with copper. PLS deprived of copper is called raffinate - a residual solution often reused in the wells (Fig. 9). The raffinate, along with containing impurities from the PLS, also usually has a low concentration of the target mineral. ECR's data suggests a copper mass of 13.2 kg/hr in raffinate, demonstrating a 98% copper extraction efficiency (Fig. 9).

A suitable chelating resin selectively adsorbs and strips the copper, removing further impurities, such as iron, from loaded organic to become an enriched electrolyte. Consequently, the copper stripping efficiency calculated for Kapunda is 54% (Fig. 9). The depleted electrolyte solution from the EW cell containing copper is often reused and mixed with the loaded organic to strip the copper.

A similar efficiency analysis conducted for the Gunnison copper project states the extraction and stripping efficiency at 92% and 58%, respectively (refer to Appendix C for calculation) (Richard Zimmerman, 2022).

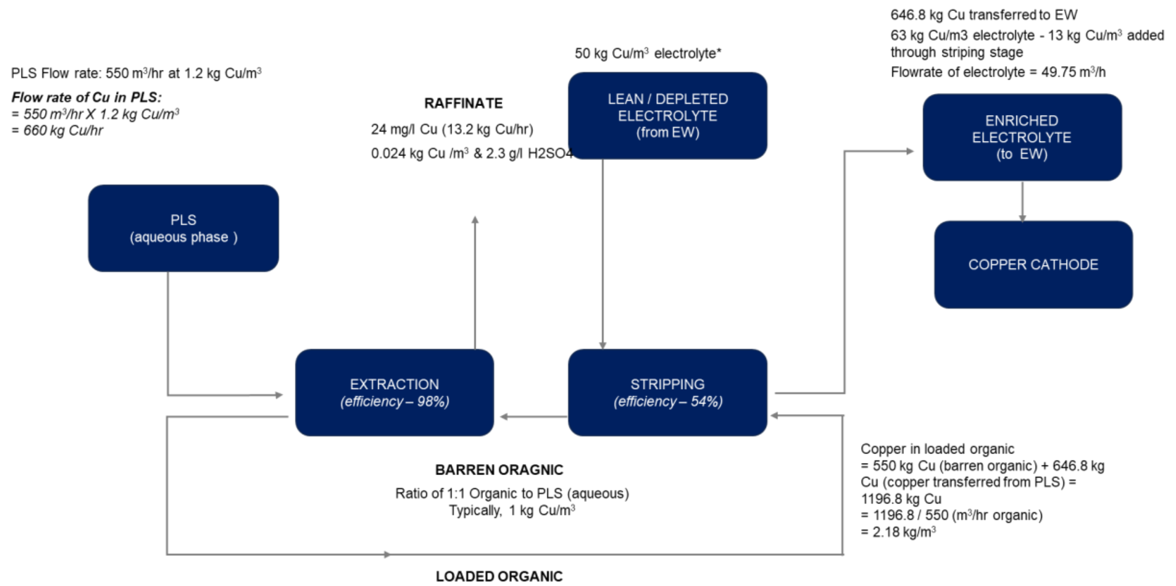

Figure 9. Kapunda's copper extraction efficiency. Detailed calculation included in Appendix B
**Assumed based on Gunnison's ratio of lean to enriched electrolyte.*

The copper extraction efficiency calculation shown in Figure 9 is unusually high. Based on a conservative approach, the study assumes a lower ore-to-concentrate efficiency at 86% and concentrate-to-cathode efficiency at 98.6% (University, n.d.). Hence, the probable copper cathode production estimate is 4,757t/yr (Table 2). The estimated ore-to-cathode efficiency at Kapunda is 84.6%.

***Table 2**. Estimating Kapunda's copper cathode production basis copper extraction efficiency*

A	PLS flow rate	m^3/hr	550	
B	Copper concentration	kg/m^3	1.2	
C	Flow rate of Copper in PLS	kg/hr	660	(A* B)
D	Mass of copper extracted @ 98% efficiency (Fig 9.)	kg/hr	647	
E	Mass of copper extracted @ 85.8% efficiency	kg/hr	566	(C*85.8%)
F	Concentrate to copper cathode @ 98.6% efficiency	kg/hr	558	(F*98.6%)
G	Hourly copper cathode production	kg/hr	558	F
H	Operational hours in a day	hours	24	
I	Daily Copper Cathode Production	tons	13	(G*H/1000)
J	Operational days in a year	days	355	
K	Probable Annual Copper Cathode	t/yr	4,757	(I*J)

4.2 Revenue Projections

The Kapunda ISR mine is projected to generate an average annual revenue of ~A$67M. The average copper cathode production is estimated at ~4,500t/yr over the mine's life, with low-capacity utilisation in the initial and final years of operations due to the mine's lifecycle.

On August 14, 2023, the LME Official Cash (spot) copper price was US$8,240/t (A$12,607/t). The LOM model assumes an increase in copper price to A$13,500/t in 2026 and a 1-1.2 % compounded annual growth rate (CAGR) over the mine's life because of the global consensus of a deficit copper market. High volatility is likely in copper prices in the next decade due to the anticipated demand-supply gap amid the transitional phase in the global energy market. Copper prices increased at 0.7% CAGR between 2010 and 2022.

4.3 Capex & Opex Costs

Initial capital investment, excluding land and exploration costs, is estimated at A$33M, and sustaining capital is estimated at A$4-5M. Wellfield development costs, including infrastructure and sustaining capital, are estimated at ~A$3M. ECR provided the well drilling cost at A$ 60K/well, and additional infrastructure and sustaining capital costs are assumed at 20% and 40% of the drilling cost. IX-EW constitutes a significant investment at 40% of total capex cost. ECR plans to deploy moving bed IX technology of two equal parallel modules, each with four 1.5-3 m diameters ion exchange columns. The estimated cost ranges from A$1,600 – 1,800/t of cathode capacity, similar to the capital cost of solvent extraction.

Additional capex includes constructing PLS and raffinate ponds, tank farm, site infrastructure, and contingency assumed at 20% of total capex.

Annual opex costs average between A$30M and A$40M. Out of which, consumables constitute more than 60% of the cost, followed by employee and energy costs.

Consumables: Spending estimate averages A$20-30M annually. MSA, the chosen lixiviant, is the highest cost contributor at an average cost of A$ 3,700/t, requiring ~3 tons for every tonne of copper. The traces of sulfuric acid in the raffinate in trial tests conducted by ECR suggest using both MSA and sulfuric acid to extract copper from the ore body. In addition to MSA, the leaching solution requires ~1.6 tons of sulfuric acid and ~1.7 tons of ferric chloride for every tonne of copper.

Employees: ECR estimates a requirement of 25 employees for copper extraction. An additional ten employees are considered for the EW process, including contingency. The annual salary factored in the LOM basis mining sector's average salary estimate of A$ 2,497 per week in 2022 (Australian Bureau of Statistics, 2023). Consequently, the yearly total staff cost stands at an average of $5M.

Energy: The ore-to-cathode production process consumes about 2,600-2,800 kWh of energy per ton of copper, with two-thirds of the power attributed to the EW process. With reliance on grid power — the total energy costs average at A$3M annually.

Others: Other costs include transportation, administrative, repairs, and maintenance costs assumed at ~7% of the total opex costs.

Royalties and taxes: Miners must pay (mineral) royalties to the government. Royalty paid on the revenue generated from the sale of the final product, i.e., in this case, copper cathode is 2% (Australia, n.d.). The corporate tax for the mining industry in Australia is 30% (Kruger, 2022).

4.4 Project Investment Appraisal

The Kapunda ISR copper mine project's present value of future cash flows, i.e., NPV, is ~A$127M at a 7% discount rate. The project’s return on investment, i.e., IRR at 42% after tax, and the time taken to recoup the initial investment, i.e., the payback period of 1-3 years. IRR is the discount rate that sets NPV to zero; if the return generated on the project investment (IRR at 42%) is greater than the cost of borrowing funds (capital cost/discount rate at 7%), the project should attract investors (Damodaran, n.d.).

Table 3. Kapunda Copper ISR Mine Project Financial Highlights

Parameters	Unit	Value
Years of Commercial Production		18
Total Copper Produced	tonnes	4,440
LOM Copper Price	Avg A$/t	15,074
Initial and Sustaining Capital Cost	A$M	38
Payback of Capital (pre-tax / after-tax)	years	1.2 / 1.7
Internal Rate of Return (pre-tax / after-tax)	%	54% / 42%
LOM Direct Operating Cost	A$/t	8,443
LOM Total Production Cost	A$/t	8,934
Pre-Tax NPV at 7.0% discount rate	A$M	195.9
After-Tax NPV at 7.0 discount rate	A$M	127.1

Discussion

The Kapunda ISR copper project shows favourable financial prospects with a positive NPV of A$127 M, a strong IRR of 42%, and a quick payback period of 1-3 years. Investors favour short payback periods – typically 3-5 years for mining companies (University, n.d.). Comparable projects like Gunnison and Florence – payback periods were 4-5 years and 2-3 years, respectively (Richard Zimmerman, 2022; Richard Tremblay, 2023). Kapunda's project appraisal emphasizes its operational viability.

5.1 Cost Comparative Analysis - Kapunda versus Gunnison and Florence

Kapunda's capex estimates per ton of capacity are the lowest at A$7,133/t compared to Gunnison and Florence (Fig. 10). Capex cost comparison is challenging across different geographies, but a few noteworthy differences arise. For example, Kapunda's per well drilling cost at A$60K is half that of Florence because of the shallow ore deposit at ~120 meters below the ground surface (versus Florence's deposit at 150-450 meters). Gunnison and Florence require setting up water treatment plants, included in other capex costs, to convert well-extracted wastewater into potable water. In contrast, Kapunda's acidic groundwater might not necessitate an extensive water treatment setup, pending pH investigation (varying groundwater pH observed).

Other ISR projects, including those in Russia, publish limited data. Even so, capex costs for the Gumeshevskoye ISR Copper Project in Russia, with a capacity of ~5,000 t/yr, were estimated at US$20M or A$28M (adjusted for purchasing power parity) in 2016. The opex estimates stood at US$2,700/t or A$3,800/t.

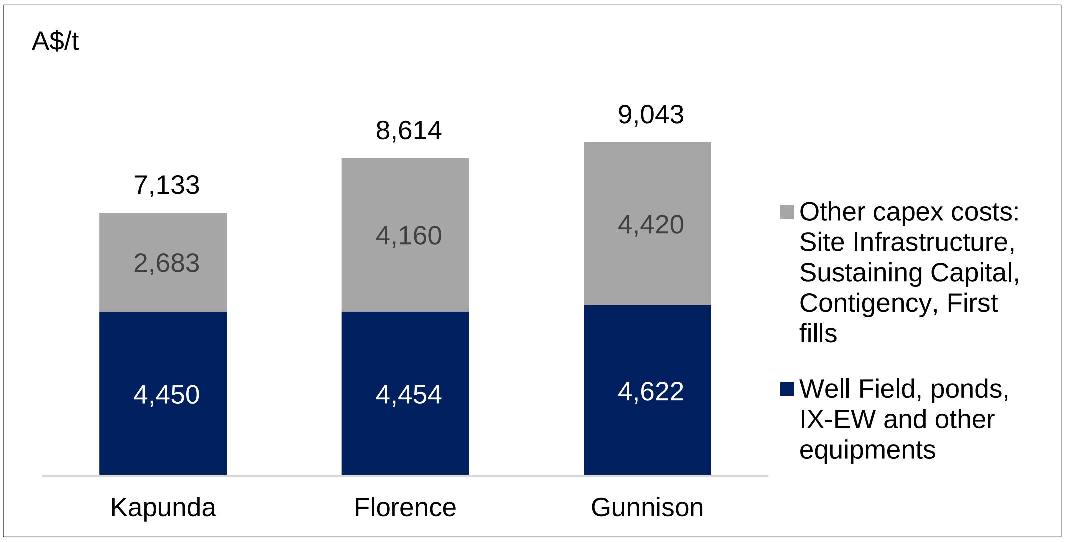

Figure 10. Capex costs comparison of Kapunda, Gunnison and Florence. Sourced from Richard Zimmerman (2022) Richard Tremblay (2023)

Kapunda's opex cost is the highest amongst the three projects (Fig. 11) at ~A$8,500/t, whereas Florence stands out for its lowest cost profile at ~A$3,300/t. Approximately 85% of the cost differentiation is due to the lixiviant costs, followed by energy and employee costs. Kapunda's preference for MSA is driven by its environmental benefits; it biodegrades in the soil in ~14 days, while Gunnison and Florence rely on sulfuric acid. Sulfuric acid's environmental impact, particularly with sulfide ores, is a concern due to acid mine drainage. MSA is a highly priced product with only a few producers globally.

The EW process's energy requirement is the highest, constituting ~65% of overall production energy. Florence boasts superior energy efficiency, requiring only 1,800 kWh/t compared to Kapunda's 2,000 kWh/t and Gunnison's 3,000 kWh/t. The energy efficiency depends on multiple factors such as equipment and process design, energy source, and heat recovery systems, to name a few Kapunda's electricity cost is double that of Gunnison, with the USA benefiting from cheaper electricity due to significant coal-based power generation.

Kapunda's productivity is markedly low at 127t/employee (industry average at ~200) due to constrained economies of scale. Consequently, Kapunda endures the highest employee cost per tonne at ~A$1,300 (at a salary parity comparison), while Gunnison is the lowest at ~A$ 450-500/t.

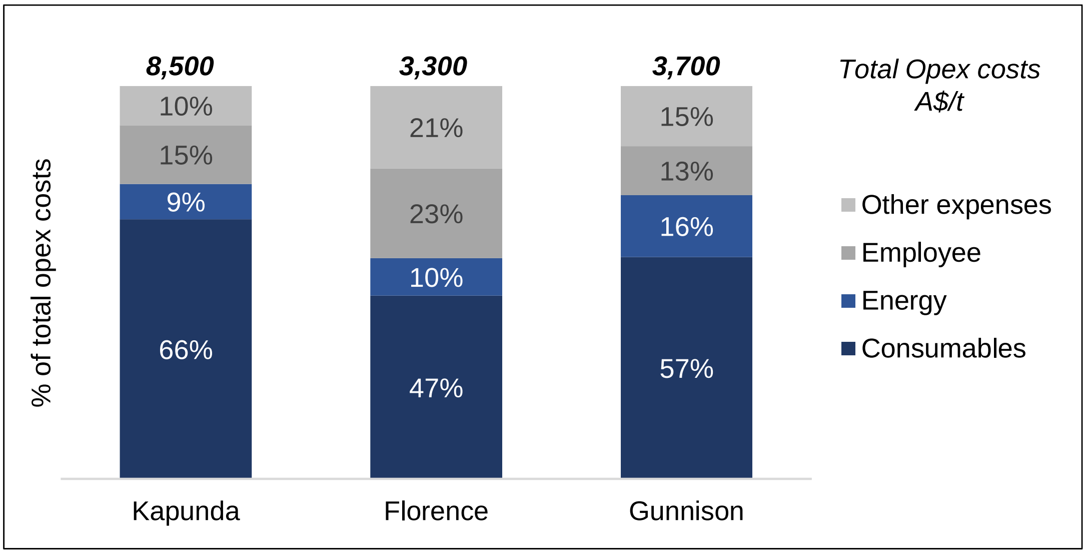

Figure 11. Opex costs comparison of Kapunda, Gunnison and Florence. Sourced from Richard Zimmerman (2022) Richard Tremblay (2023)

5.2 Scenario Analysis

The positive NPV for the Kapunda ISR copper mine project indicates its financial feasibility to proceed for approvals and thereafter operations. The scenario analysis evaluates the risk pertaining to seven variable parameters (Table 4).

Table 4. Variation range between -20% to +20% from baseline for scenario analysis to assess NPV

Variables	Pessimistic	Baseline	Optimistic
Utilisation rate	75%	83%	90%
Copper Price	12,059	15,074	18,089
Energy Price	0.22	0.28	0.33
MSA Price	976	1,220	1,464
Ferri Chloride Price	444	554	665
Sulfuric Acid	163	203	244
Royalty	1.0%	2.0%	4.0%

The scenario analysis (Table 5) reflects the project viability in baseline, pessimistic, and optimistic scenarios:

- Baseline scenario: includes variables at average unit value over the life of mine. For example, LME copper price at A$15,074/t (Table 5) is the average price over 18 years.
- Optimistic scenario: indicates the highest possible upside in the event of favourable outcome for all variable factors.

- Pessimistic scenario: where the analysis includes the highest cost factors and lowest revenue factors in the assumed range between +/-20%, indicating a borderline NPV (after-tax) at ~A$2M. If the LME copper price falls below A$12,000/t, keeping everything else constant in the pessimistic scenario, the project NPV will be negative and financially unviable.

Scenario analysis identifies a project's best and worst outcome. However, it is challenging to explore multiple scenarios simultaneously.

Table 5. Scenario Analysis of Kapunda ISR copper mine project

Parameters	Unit	Pessimistic Scenario	Baseline Scenario	Optimistic Scenario
Total Copper Produced	tonnes	3,994	4,440	5,059
LOM Copper Price	Avg. A$/t	12,059	15,074	18,089
Payback of Capital (pre-tax / after-tax)	years	5.4 / 7.8	1.2 / 1.7	< 1
Internal Rate of Return (pre-tax / after-tax)	%	15% / 10%	54% / 42%	83% / 65%
Pre-Tax NPV at 7.0% discount rate	A$M	17.3	195.9	396.0
After-Tax NPV at 7.0 discount rate	A$M	2.1	127.1	267

5.3 Sensitivity Analysis

A tornado chart (Fig. 12) ranks LME copper price and MSA price as the top two drivers influencing NPV (Fig. 12). MSA price and capacity utilization rate have almost equivalent NPV, with sulfuric acid price least influencing the NPV.

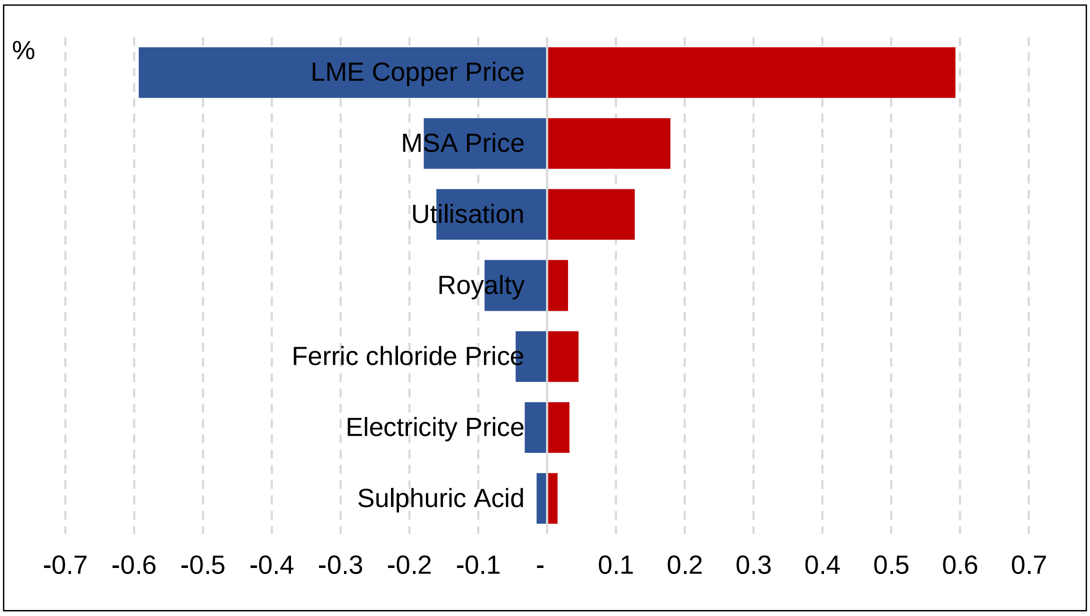

Figure 12. A tornado chart depicting percentage impact of each of the seven uncertain variables on NPV

A sensitivity analysis highlights fluctuations across most variable factors, excluding copper price, resulting in NPV between A$100M and A$150M (Fig. 13). Figure 13 concludes that the impact of variables other than copper price on NPV is moderate.

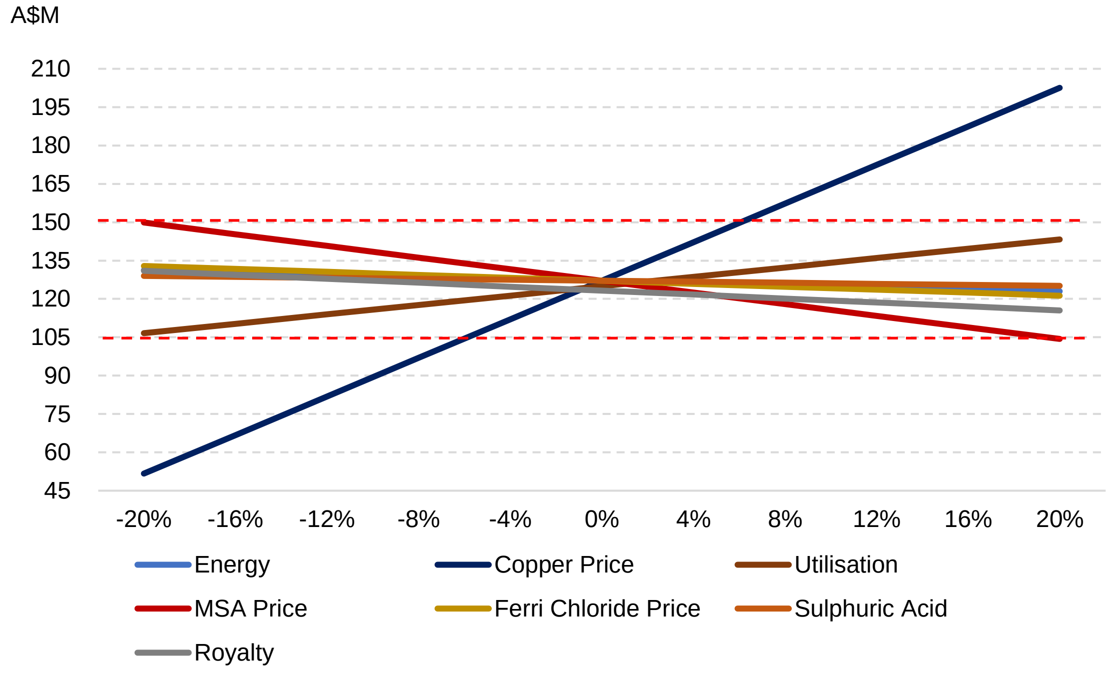

Figure 13. NPV outcome sensitive to fluctuations in uncertain variables at regular intervals

5.4 Monte Carlo Simulation

Expanding on the investment appraisal analysis and extending the scope of the sensitivity analysis, Monte Carlo Simulation, a statistical risk assessment model, was run to assign the likelihood of NPV to randomness in uncertain variables for 1000 iterations, yielding an average NPV of A$124M and 90% confidence interval that the NPV value of the project will lie between A$68M and A$178M. The values are comparable to pessimistic and optimistic scenario NPV values at A$2M and A$267M. The simulation indicated a low – less than 5% probability for the NPV being A$2M. Generally, a probability below 5% is considered negligible and outliers.

The simulation model solidifies the LOM analysis, stating a 56% probability that the project NPV will be less than or equal to A$130M (Fig. 14), closer to our baseline scenario.

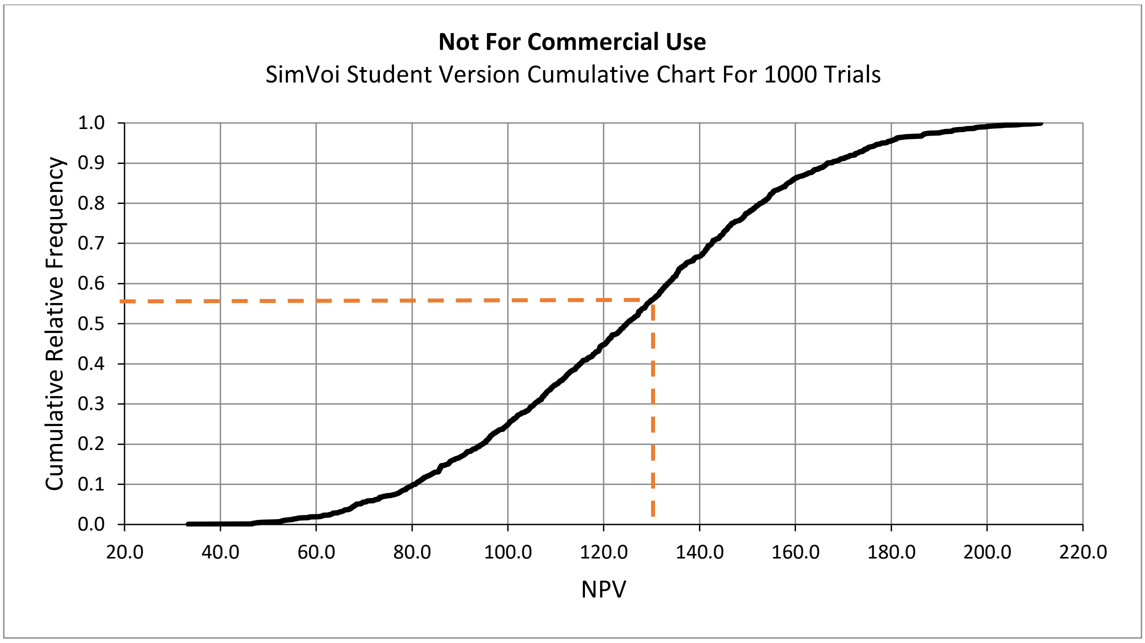

Figure 14. 'Probability of occurrence assigned to NPV, using triangular probability distribution, factoring randomness in uncertain variables for thousand iterations

5.5 Recommendations

5.5.1. Explore alternative energy source and efficiency to save costs

Kapunda's operating costs are significantly higher, 2-2.5 times that of Gunnison and Florence, and is a concern area for investors. Energy cost at an average of A$750/t of copper produced is a key contributor. It is higher than A$580/t for Gunnison and A$315/t for Florence (Richard Tremblay, 2023; Richard Zimmerman, 2022). To enhance profitability and project NPV, implementing measures to reduce costs is imperative. For example, a modest 10% reduction in power price translates into a reduction of A$75/t in energy cost and improves NPV by A$2M. Kapunda location is apt for in-house solar power generation to substitute grid power to lower energy costs. In 2022, solar and wind contributed 70% to South Australia's electricity generation (Australia, 2022). In 2030, the levelized cost of electricity for a large solar photovoltaic (PV) plant is projected at A$40/MWh, significantly lower than the grid power price considered for the project (Paul Graham, 2020; Ernst & Young (EY), 2019). The Kapunda ISR copper mine project would require a vast capacity of at least 14,000 MW. The solar PV plant offers a promising low-cost solution; however, a thorough economic assessment is necessary to assess the challenges related to project scale, land availability, and power storage (Paul Graham, 2020) and evaluate if the cost savings can be achieved.

5.5.2 Evaluate the economics for the sale of copper concentrates instead of cathode

Another area worth exploring would be the economic assessment of selling copper concentrates as a finished product instead of copper cathode. This assessment will eliminate the capital and energy-intensive EW process – costs associated with treating and refining copper, which the smelter bears. The treatment and Refining Charges (TC/RCs) charges in 2021 were the lowest at US$59/t since 2012 (Metso, 2021). The low TC/RCs indicate supply tightness in the concentrate market. With the global consensus on the scarcity of future copper supply, the timing offers an opportune moment to explore this alternative approach. Copper concentrates sell at a discount to LME-listed high-purity copper prices, factoring in the TC/RCs charges.

5.4 Limitations

The LOM model accuracy is in the +30% to -30% range; supplier quotes can help achieve greater precision, particularly for capex, primarily based on other ISR projects. Consumables used for ISR mining are not bulk traded except sulfuric acid, and hence, the price data availability limits accuracy. Some consumables, such as chelating resin, are tailored and trademarked by companies and often require trials to lock in a suitable resin. Given that the project is still in the early stages of developing a mining proposal, there is no information on trials; hence, it is a black box.

ECR suggests an increase in copper mining to 20,000-30,000 t/yr of Cu from 5,000 t/yr through horizontal drilling; however, at this stage, the estimates' possibility and accuracy are doubtful and excluded from the LOM model. The study also excludes revenue generation from the by-product, gold, for the Kapunda ISR copper-gold mine.

Significant delays in project execution could change the NPV drastically due to cost overruns. The study assumes 100% equity financing for the project due to limited information on the proposed capital structure from the company. The working capital funding to ensure funds for day-to-day operations is assumed using internal accruals. Generally, companies use working capital loans (tenured a year) at the bank interest rate. The loan's interest rate payments negatively impact profitability and overstate cash flows, inflating NPV. To counter this effect, the depreciation, a non-cash element, is not added back to profit.

Conclusion

The paper establishes the economic viability of the Kapunda ISR copper mine project in South Australia. It highlights the need for innovative mineral extraction technologies, especially for copper.

The study estimates Kapunda's annual copper production by calculating the copper extraction efficiency from extensive field tests conducted by ECR. The calculation showed copper extraction efficiency at 98%. However, subsequent research to cross-verify the calculation revealed it to be unusually high. With a conservative approach, the efficiency was adjusted to ~86% based on Princeton University research. The estimated average copper cathode production at Kapunda ISR mine is ~4,500t/yr.

The LOM created for Kapunda proclaims the project's annual revenue potential at ~A$67M. The model, indicating the capex and opex costs and peer cost per ton analysis, will serve as a guiding reference for future ISR copper projects in Australia. The DCF-based project NPV is A$127M, with an IRR of 42% and a payback period of 1-3 years, which provides a lucrative proposition for investors.

Additionally, a second simulation (scenario analysis) integrates a dynamic assessment of uncertain variables such as capacity utilization rate, copper price, and consumables prices, providing the lowest NPV value to state the bottom-out risk for the project at A$2M and the highest at A$267M. A negative NPV would indicate that the project is unviable and may not receive funding for operations.

A third simulation analysis computed the NPV at A$124M by conducting a Monte Carlo simulation. The simulation model demonstrates 90% confidence that the NPV value for the project lies between A$68M and A$178M, reaffirming the project's viability.

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Appendices

Appendix A: Detailed Information Sources and Assumptions for LOM model

	Unit	Value	Source / Notes
Purchase Power Parity US to AUD (2022)		1.42	OECD
Copper Price			
LME Copper Cash Official Price in first year of operation 2026	US$/t	9,000	LME / In 2024, World Bank expects copper at USD 8,000 per tonne, Department of Industry, Science and Resources, Australia expects copper at USD 8,500 per tonne. Average considered + price inflation assumed at 3% for two years
USD/AUD		1.5	

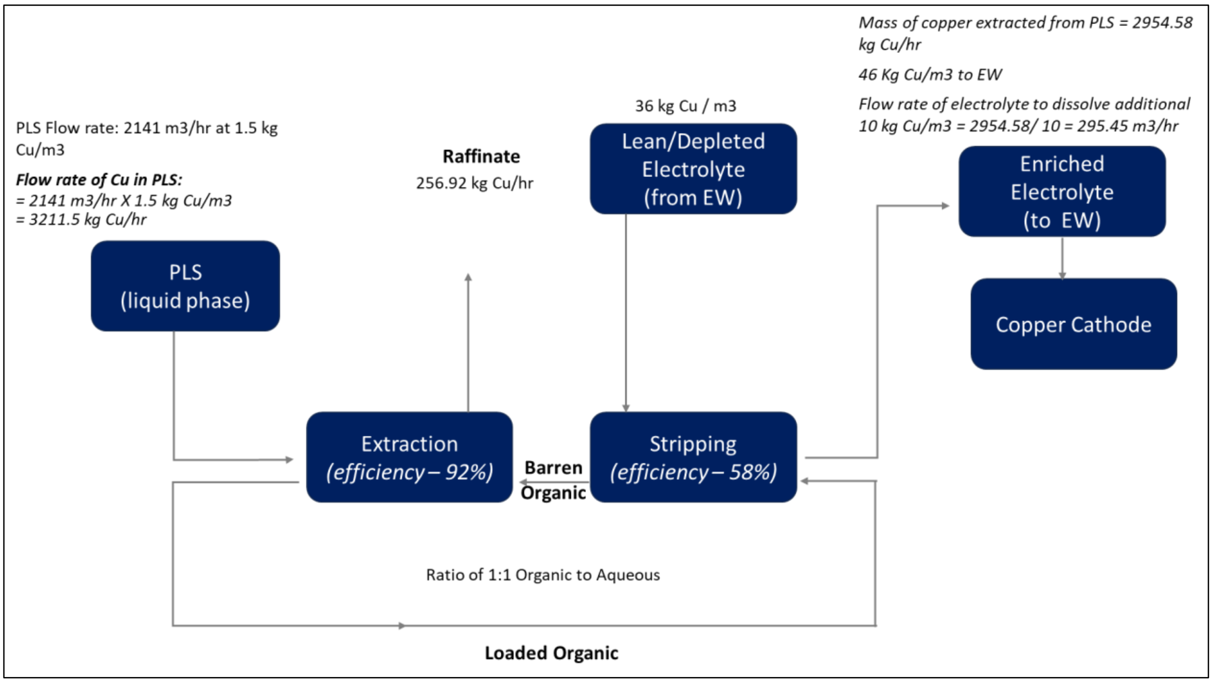
LME Copper Cash Official Price in first year of operation 2026	A$/t	13,500	
Price change CAGR	%	1.1%	From 2010 to 2022, Copper LME CAGR 0.7%, higher CAGR expected due to copper shortage, mine closures, demand from energy transition
Capital Costs			
ISR Wellfield			
No of Wells	Nos	19	ECR Kapunda ISR Project - Scoping study; Range provided 10-20 wells
Other wells - monitoring and contingency	Nos	10	Assumption
Total nos of wells		29	
Drilling cost per well	A$	60,000	ECR
Wellfiled installation and infrastructure	%	20.00%	Gunnison and Florence ISR project Pre-Feasibility/Feasibility Reports
Wellfield Sustaining Capital	%	40.00%	Gunnison and Florence ISR project Pre-Feasibility/Feasibility Reports
Other Processing Capex & Contigency			
Lined PLS and Raffinate ponds	A$/t	450	Gunnison ISR Project Pre-Feasibility Report
Tank Farm for handling process liquids	A$/t	525	Gunnison ISR Project Pre-Feasibility Report
IX Plant	A$/t	1,700	Honeymoon Project
Electrowining	A$/t	1,000	Gunnison and Florence ISR project Pre-Feasibility/Feasibility Reports
Automated Stripping Machine	A$/t	253	Gunnison ISR Project Pre-Feasibility Report
Infrastructure	%	10%	Assumption @ 10% of processing fixed cost
Sustaining Capital	%	20%	Assumption @ 20% of processing fixed cost
Contigency	%	20%	Assumption at 20% of total capex costs
Opex: Consumables			
Methanesulfonic acid - Lixiviant	t/unit	3.05	Chemical reaction formula between copper oxide, MSA, sulfuric acid, and ferric chloride
Sulfuric Acid - Wellfield	t/unit	1.56	Chemical reaction formula between copper oxide, MSA, sulfuric acid, and ferric chloride
Ferric Chloride - Oxidant	t/unit	1.71	Chemical reaction formula between copper oxide, MSA, sulfuric acid, and ferric chloride
Methanesulfonic Acid (MSA) Price			
	A$/t	1,100	ECR
Sulfuric Acid - Wellfield	A$/t	199	ECR
Ferric Chloride - Oxidant	A$/t	500	International Trade Centre UNCTAD/WTO (ITC)
Chelating Resin	%	10%	Assumption - % of MSA, sulfuric acid and Ferric Chloride total costs
Other consumables	%	2%	Assumption - % of MSA, sulfuric acid and Ferric Chloride total costs
Opex: Energy			
Energy Costs at Kapunda	A$/kWh	0.25	ECR; Grid power supply
Annual Increase in energy costs	%	1.2%	
Energy Requirements by Process			
Well Field	kWh/t Cu	311	Florence ISR Project Feasibility Report
Neutralization	kWh/t Cu	31	Florence ISR Project Feasibility Report
SX Plant	kWh/t Cu	259	Florence ISR Project Feasibility Report
EW Plant	kWh/t Cu	2,000	ECR
Reagents, Tank Farm, Ancillaries	kWh/t Cu	93	Florence ISR Project Feasibility Report

Water Management	kWh/t Cu	195	Florence ISR Project Feasibility Report
Opex: Labour			
Wellfield to IX	Nos	25	ECR
EW	Nos	5	Assumption
Contingency @ 15%	Nos	5	Assumption
Total Labour	Nos	35	
Australian Annual Average Pay	A$/employee	1,30,000	Australian Bureau of Statistics AUD$ 2497 per week in 2022
Annual Wage hikes	%	2%	
Opex: Repairs Maintenance	%	5%	ECR Kapunda ISR Project - Scoping study; Assumption - % of capex cost
Opex: Other costs	%	2%	Assumption - % of total energy, consumables, and employee costs
Government Royalty Rate	%	2%	
Corporate Tax Rate (Australia)	%	30%	

Appendix B: Detailed calculation of Kapunda's copper extraction efficiency

- Extraction efficiency = 660 kg Cu (copper in PLS) minus 13.2 kg Cu/hr (copper in raffinate) by 660 kg Cu/hr (copper in PLS)
- Stripping efficiency – 646.8 kg Cu /hr (copper transferred to EW) by 1196.8 kg Cu/hr (copper in loaded organic)
- Copper transferred to EW:
  = 1196.8 kg (loaded organic) - 550 kg Cu (barren organic; 1 kg Cu/m3 * 550 m3)
  = 646.8 kg Cu transferred to EW
- Flowrate of electrolyte = 49.75 m3/h
  The flowrate of electrolyte through the stripping stage - 646.8 kg of Cu per hour is stripped from the organic by the electrolyte, and 13 kg Cu is added to the electrolyte per m3 of the solution per hour, therefore: 646.8 / 13 = 49.75 m3/h flowrate of electrolyte required to dissolve an additional 13 kg of copper per m3

Appendix C: Gunnison copper extraction efficiency



Appendix D: Specific consumption MSA, sulfuric acid and ferric chloride based on chemical reaction with copper oxide

$$CuO + H_2 \rightarrow Cu + H_2O$$

$$2Cu\ (OH)_2 \rightarrow 2CuO + 2H_2O \textbf{ or } Cu\ (OH)_2 \rightarrow CuO + H_2O$$

$$CuCl_2 + 2NaOH \rightarrow Cu\ (OH)_2 + 2NaCl$$

$$3CuSO_4 + 2FeCl_3 \rightarrow Fe\ (SO4)_3 + 3CuCl_2 \textbf{ or } CuSO_4 + 2/3\ FeCl_3 \rightarrow 1/3\ Fe2(SO4)_3 + CuCl_2$$

$$Cu\ (CH_3SO_3)_2 + H_2SO_4 \rightarrow Cu\ (SO_4) + 2CHO_3S$$

$$CuO + 2CH_4O_3S \rightarrow Cu\ (CH_3SO_3)_2 + H_2O \textbf{ or } ½\ CuO + CH_4O_3S \rightarrow ½\ Cu\ (CH_3SO_3)_2 + ½\ H_2$$

	Cu	CH_4O_3S	H_2SO_4	$FeCl_3$
Moles	n/2	n	n/2	2/3 x n/2 = n/3
Ratio	1	2	1	2/3
Mass flow rate* (mol/hr)	10476.19	2 x 10476.19 = 20952.38	10476.19	2/3 x 10476.19 = 6984.17
Mass flow rate (kg/hr)	(10476.19 X MM) /1000	(20952.38 X MM) /1000	(10476.19 X MM) /1000	(6984.17 X MM) /1000
Molecular mass (MM)	63	96	98	162
Mass flow rate (kg/hr)	659.99	2011.42	1026.66	1131.42
Specific consumption for 660 kg/hr copper in PLS flow rate	0.66	2.01	1.027	1.13
Specific consumption for 1000 kg/hr copper PLS flow rate	**1.0**	**3.05**	**1.55**	**1.71**

*Copper moles produced per hour:

Given by ECR

- Solution flow rate = 550m3/hr
- Copper concentration = 1200 mg/l

Calculation:

- Copper produced = 1200 X 500 X 1000 / 1000
- Copper molecular mass = 63
- Copper moles produced = 1200 X 500 / 63 = **10476.19 mol/hr**