TECK'S CESL COPPER PROCESS:
A COMMERCIAL READY CONCENTRATE LEACH ALTERNATIVE

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ABSTRACT

As replacement production from global refined copper rises, the need for producers to find cost effective ways to develop copper porphyry deposits is becoming increasingly important. For example, brownfield projects in South America with depleting heap leach production but with an underlying sulphide deposit represent an opportunity to integrate concentrate leaching with existing solvent extraction and electrowinning infrastructure to establish value added on-site metal production as an alternative to conventional concentrate sales. This option can accelerate the delivery of metal to market while avoiding permitting and cost issues related to long slurry pipelines. Over the last 20 years, Teck Resources Limited ("Teck") has been at the forefront of developing copper pressure leaching technology, known as the CESL Process, which has been tested at an industrial scale and has the potential to achieve cost competitive cathode production while effectively handling impurities in concentrates which render them difficult to market. This paper highlights the successful development history of Teck's copper pressure leaching technology while providing standard operating parameters and resulting metallurgical performance from a range of primary copper sulphide concentrates tested. A conceptual level case study is presented to assess the integration of a commercial pressure leach circuit with existing SX/EW infrastructure. The technical, economic, environmental and social value-added benefits of this alternative will be compared to conventional concentrate marketing to smelters.

INTRODUCTION

Teck has developed extensive hydrometallurgical and pyrometallurgical expertise at its mining and smelting-refining operations in the production and processing of a variety of base- and precious-metal concentrates to recover a range of metals including copper, nickel, cobalt, zinc, lead, germanium, indium, silver and gold. Over the past 20 years Teck has invested in the development of Cu, Cu-Ni, Cu-Au, Cu-Mo and Cu-Zn hydrometallurgical processes collectively known as the CESL Processes which are patented and proprietary to Teck. These technologies have been rigorously tested and developed and are being evaluated for various commercialization opportunities. Teck's CESL hydromet group, located in Richmond, BC is focused on developing hydrometallurgical solutions which create value for Teck's mining operations, undeveloped mining projects or partners' operations and projects.

This paper focuses on highlighting the successful development of Teck's CESL Copper Process including its consistent metallurgical and operating performance achieved through several comprehensive technical programs and projects. A strong case for its use as a capital efficient alternative to conventional concentrate sales is in the integration of concentrate leaching technology with existing solvent extraction and electrowinning infrastructure for on-site metal production. Several key value creating benefits realized through this application is highlighted.

BACKGROUND

Global copper mine supply is largely sourced from primary sulphide mineralization (~80%) which is mined and processed to copper concentrates using conventional flotation technology [12]. Despite sizeable capital investments and lengthy permitting challenges, high-pressure slurry pipelines have proven to be an economically viable means for long distance, cross country transportation of concentrate from remote mine site locations to port facilities where material is dewatered and shipped to downstream processing markets, the majority of which are offshore [1,6]. In spite of evermore stringent environmental standards on pyrometallurigcal process emissions and management of waste materials, smelting and refining technology remains the industry standard for treating traditional copper concentrates as it is an energy efficient and low cost process [12].

Supergene mineralization makes up the balance (~20%) of global copper mine supply and it is processed and refined through hydrometallurgical heap leaching-solvent extraction-electrowining technology to produce saleable cathodes. The case for adopting hydrometallurgical leaching technology for primary sulphides, particularly minerals such as chalcopyrite, has been in development for over 40 years [10]. To date, several hydrometallurgical leaching technologies have gained acceptance in niche situations such as those where concentrates are not amenable to modern smelting and refining technology due to complex mineralogy or the presence of deleterious elements such as arsenic. That said, in order for hydrometallurgical leaching of traditional copper concentrates to be considered a viable alternative to smelting and refining, future applications of innovative leaching technologies not only need to be cost competitive in order to pay back their required capital investment, they should also be beneficial from a community and sustainable development perspective which in many cases they have shown significant potential for generating environmental and social value-added benefits.

Underinvestment in previous years coupled with strong copper demand from large emerging market economies such as China has resulted in the recent expansion in capital projects [1]. Unfortunately a real industry challenge has been rising development costs which have seen an average escalation of ~20% (from 2004 to 2012) largely due to a number of contributing factors including substantial infrastructure requirements, shortage of skilled labour, higher raw material input costs, increased environmental and community costs associated with new projects [1]. As a result, the need for producers to find capital efficient solutions for the development of new copper porphyry deposits is becoming increasingly important to the success of the industry. Integrating concentrate leaching technology with existing solvent extraction and electrowinning infrastructure for on-site cathode production offers a cost competitive alternative to conventional concentrate sales with additional value-added benefits to be realized. Several existing copper mining operations in South America have depleting heap leach reserves with large underlying sulphide deposits [1]. Projects such as these represent a potentially attractive opportunity to implement Teck's CESL Copper Process.

The CESL Copper Process is as a medium temperature pressure leach for sulphide concentrates in the presence of chloride catalytic ions (12 g/L). In most cases a light re-grind of the mill concentrate is necessary to reduce particle size. Grinding the concentrate increases the surface area of the particles which improves the oxidation and recovery of the copper minerals in an autoclave. Using high purity oxygen sparging, copper minerals are oxidized in an autoclave at 150 °C and 200 psi. The oxidized minerals are leached into solution in an autoclave or from the pressure oxidation solids with acidic raffinate at atmospheric conditions depending on the pyrite content in the concentrate. Sulphur in the concentrate is primarily oxidized to elemental sulphur instead of sulphate. The presence of chloride in the autoclave helps to increase the rate of reaction and reduce sulphur oxidation. The low sulphur oxidation achieved in the process decreases operating and capital costs, and thus allows for economic recovery of metals [5]. Excess sulphate (acid) is removed from the process through neutralization and gypsum production.

Following pressure oxidation, the slurry from the autoclave is discharged into a standard pressure letdown system. A thickener followed by filtration separates the pregnant leach solution (PLS) from the leach residue. PLS is sent to the copper solvent extraction circuit for selective copper recovery using a commercial organic extractant. The extractant is loaded with copper and then washed to remove entrained chloride and impurities. After washing the organic, the copper on the extractant is stripped into a pure copper electrolyte, providing the feed to copper electrowinning. LME Grade A copper cathodes (99.999% Cu) are produced under conventional electrowinning conditions.

An evaporator is used to maintain the plant water balance. Any water additions to the plant that are in excess of the flash steam from pressure oxidation, the evaporation from heated tanks, or the entrained solution in the solids, must be removed by the evaporator as condensate to ensure a stable plant balance. These water additions include grinding water, reagent makeup water, and wash solutions. Figure 1 provides a simplified diagram of the CESL Copper Process.

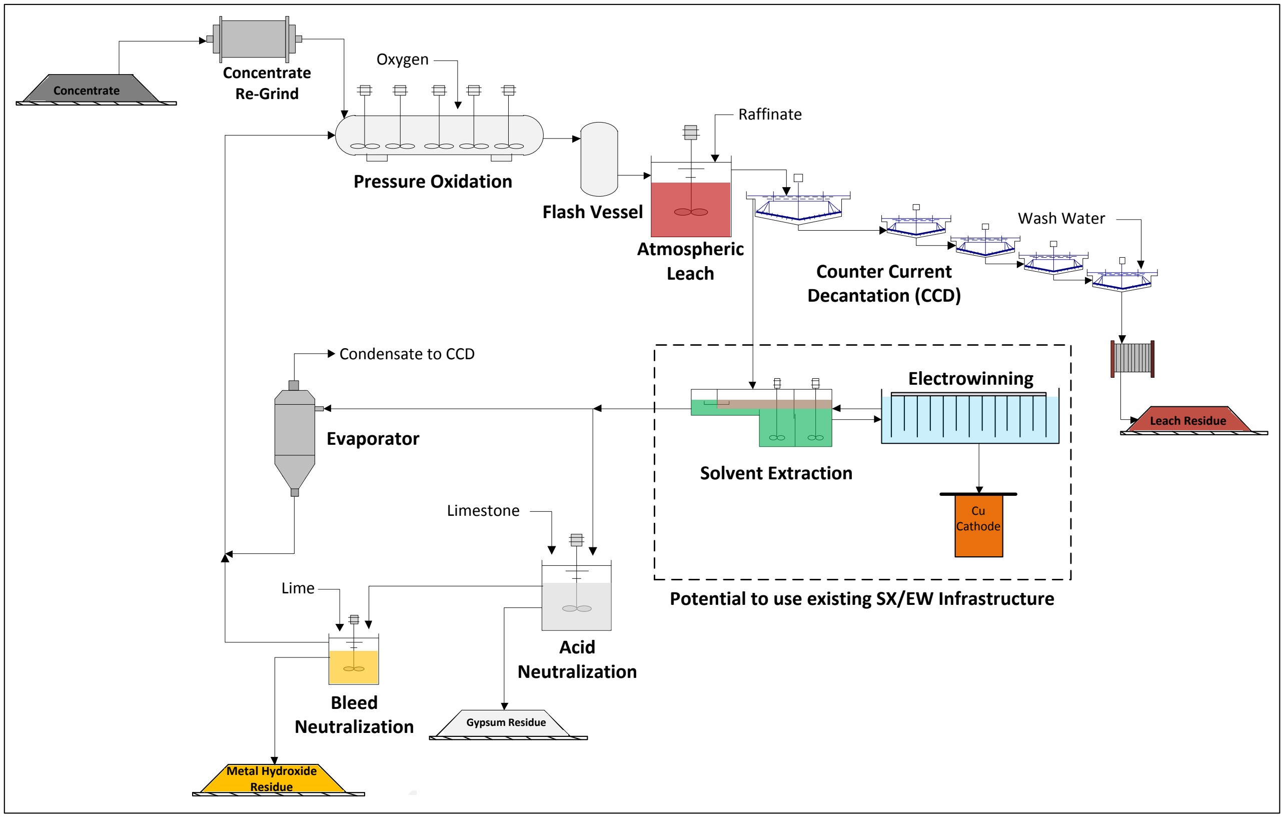

Figure 1 - Simplified CESL Copper Process Diagram

DEVELOPMENT HISTORY OF CESL COPPER PROCESS

Teck's CESL Copper Process was developed as an alternative to conventional smelting and refining of copper concentrates for the production of LME Grade A copper cathode [5]. As shown in Figure 1, the technology is based on the combination of a few well-known and established industrial processes (i.e. pressure leaching, solvent extraction and electrowinning) decreasing potential problems with operability resulting from complex process equipment. The technology has been well tested at bench (laboratory scale), pilot and demonstration scales for over 25,000 hours of continuous operation, and has successfully processed over 1,500 tonnes of copper concentrates of varying mineralogical composition. The staged development approach Teck applied to the CESL Copper Process was undertaken to mitigate risks associated with start-up including slow ramp-up periods and failure to achieve design performance (i.e. quality and/or throughput) of future commercial operations.

The benefits of the staged development approach was best demonstrated from 2008 through to 2010 when Vale successfully constructed and operated a 10,000 tpa industrial scale leach plant based on the CESL Copper Process in the Carajás region of Brazil to process locally sourced copper concentrates [4]. Built with the main purpose of validating the process at a commercial scale while training locally sourced personnel, the plant ramped up quickly and was successfully operated as designed without serious health and safety incidents. After commissioning, the leach plant largely operated between Series I (mature technology, standard equipment and/or thorough testing) and Series II (prototype, first licensee, first-of-a-kind, insufficient front-end loading, FEL) of the McNulty's series concept for technologies as described by Kennedy et al. [7]. Upon completion of the project no process flaws or significant design changes, as recommended and presented by Teck to Vale, were identified in the operation of the facility.

From inception the CESL Copper Process was designed to maximize the recovery of copper from concentrates while minimizing the overall cost and environmental footprint of producing copper cathode. At its world class hydromet pilot facility in Richmond, British Columbia, Teck has consistently demonstrated its ability to convert varying qualities of copper concentrate into LME Grade A copper cathode while producing only gypsum, elemental sulphur and hematite as stable residues resulting from the process. In contrast, traditional smelting and refining is becoming increasingly difficult to operate sustainably due to the environmental impact caused by the production of sulphur dioxide, solid wastes in the form of slag, and heavy-metal (Sb, As, Cd, Hg) bearing materials such as flue dust and particulate emissions. Recently, Teck and Aurubis, Europe's largest copper producer and leading processor of complex custom concentrates using environmentally sound state of the art technologies, have formed a partnership to work together on advancing the application of CESL copper-gold technology for the development of high arsenic bearing copper resources [8].

Through the completion of several comprehensive metallurgical and engineering studies, Teck has demonstrated that the CESL Copper Process is capable of converting a wide range of copper concentrates to copper cathode at a cost which is very competitive in comparison to competing refining technologies. Historical scoping, pre-feasibility and feasibility studies were completed by third party engineering and consulting firms and suggest the capital costs of a CESL copper leach plant are lower compared to other competing hydrometallurgical leaching and refining technologies and the implementation risk is less due to its thorough development. The process has the additional benefit of reducing shipping costs for concentrate producers that are located remote from smelter customers and/or low cost transportation infrastructure. Teck has completed evaluations of several copper concentrates produced around the world under CESL Copper Process leaching conditions. The results of that test work consistently demonstrate high copper recovery from concentrate (>96%) at industry competitive processing costs, a significant improvement in downstream costs (mainly lower shipping costs) and the possibility of increasing overall metal recovery through the mill due to the capability of the CESL Copper Process to successfully treat lower grade copper concentrates.

METALLURGICAL PERFORMANCE

Copper Leaching

CESL technology has processed copper concentrates generated from over 100 different copper deposits. The difference between such concentrates is primarily mineralogy, coupled with grade and impurity composition. Table 1 presents pilot plant metallurgical results from six different concentrates, labeled concentrate A through F. The results indicate high copper extraction for all concentrates, with a positive correlation between concentrate grade and extraction. The pyrite grade of the different concentrates is also presented given its influence on sulphur oxidation, where low sulphur oxidation is beneficial to overall economics. This work demonstrates the capability of the CESL Copper Process to process a wide range of concentrates with diverse mineralogical characteristics and metallurgical complexity.

Table 1 - CESL Copper Process Metallurgical Results

	Feed Material		Metallurgical Results	
	Cu Grade (%)	Pyrite Grade (%)	Copper Extraction (%)	Sulphur Oxidation (%)
A	19	1	97	7
B	22	1	97	6
C	26	10	98	19
D	37	16	98	20
E	41	5	99	10
F	48	0.5	99	5

The technology has also shown the ability to effectively process penalty elements within concentrate that smelters traditionally have difficulty managing. Table 1 presents smelter penalty elements, typical smelter penalty limits, and the grade of the respective penalty element processed using CESL technology.

Table 2 – Impurity Bearing Concentrates Tested at CESL

Element	Limit[12]	Grade tested	Comment
Arsenic	0.2%	>10%	- Precipitates in the residue as stable form (scorodite) [2,8]
Antimony	0.05%	>0.6	- Does not react, deports to residue in a stable form
Bismuth	0.02%	>3%	- Does not react, deports to residue in a stable form
Chlorine	0.03%	>0.03%	- Leach extent dependent upon mineralogy; leaching beneficial as Cl added to process as lixivant
Fluorine	0.03%	>0.4%	- Leach extent dependent upon mineralogy; use of Ti MOC enables the processing of such concentrates
Mercury	5ppm	>500ppm	- Leach extent based on autoclave acidity; can control to <10% or >90% (as desired)
Nickel	0.50%	>2%	- Leaches near quantitatively. Opportunity to recover as byproduct
Uranium	--	>0.02	- Leach extent based on autoclave acidity; can control to <10% or >90% (option for byproduct)
Zinc	3.0%	>3%	- Leaches near quantitatively. Opportunity to recover as byproduct

Through extensive testing, CESL has demonstrated that the majority of impurities deport to the residue in a stable form [2,8]. Some metals that are not typically paid for by copper smelters (e.g. Co, Ni, U, Zn), or are a penalty, can be valuable byproducts through hydrometallurgical processing.

The process is able to treat impurities such as chlorine and fluorine that cause corrosion challenges for pyrometallurgical and other hydrometallurgical processes. CESL technology requires chloride (12 g/L) for complete oxidation of chalcopyrite type minerals, thus the construction materials used in the plant are designed to handle chlorine and fluorine.

The ability to process chloride bearing water has benefited the process through the use of seawater, brine or gray water as process water. This minimizes fresh water requirements to the process largely to makeup water for the electrolyte and gland water. In general, process water requirements for the technology are low ($<5t_{H2O}/t_{conc}$) given the closed water balance which is achieved through the use of an evaporator and small quantity of residue generated (~1t $_{residue}/t_{conc}$).

As the majority of copper concentrates contain appreciable gold and silver values, effective recovery of these metals is an intrinsic part of any refining technology. Through the use of the CESL Gold Process, economic recovery (≥ 90%) of precious metals has been demonstrated on numerous concentrates [10].

Copper Recovery

The pressure leaching of sulphide concentrates produces copper concentrations in the PLS (Pregnant Leach Solution) that are higher (~40 - 50 g/L Cu) than typical heap leach operations. The integration of pressure leaching into a heap leach operation with depleted reserves allows for the utilization of existing solvent extraction and electrowinning circuits by increasing reagent concentration to allow for increased delta copper requirements. The integration is highly flexible in terms of what commercial extractant is used, as various industry leading reagents have been thoroughly demonstrated on continuous piloting by Teck's hydromet group [9].

Through extensive testing of various concentrates, configuration of the solvent extraction circuit can be varied from one to four separate stages (each operating with two counter current mixer/settlers) of extraction dependent on the concentrate grade, mineralogy, and whether there are existing mixer-settler trains at the brownfield site to integrate the pressure leaching circuit. Each configuration contains a wash stage to scrub off any chloride that may be entrained in the organic solution and small amounts of iron that are chemically loaded on the organic. The organic is stripped in a two stage counter current process.

Copper electrolyte produced from solvent extraction contains minimal impurities such as iron at less than 300 ppm, allows for high current efficiency and lower operating costs to be achieved in the cellhouse. Due to the high purity of the advanced electrolyte, cathodes produced are higher than LME Grade A specifications, forecast to achieve 99.999% purity for a wide range of copper concentrate quality.

CONCEPTUAL CASE STUDY

This section presents a conceptual level case study to assess the integration of a commercial CESL concentrate leach plant with existing solvent extraction and electrowinning (SX/EW) infrastructure. A financial assessment is provided comparing on-site cathode production, and shipping by truck versus building a 150km concentrate pipeline with dewatering, storage and handling facilities at a nearby existing port to receive concentrate and then ship to traditional downstream smelting and refining markets in Asia.

For this conceptual case study, it is assumed that supergene mineralization for a heap leaching-solvent extraction-electrowining operation with up to 150,000 tpa cathode production is nearing the end of its resource life and will soon transition to a sulphide concentrator project. Located in a major South American copper producing district, the open pit sulphide operation is expected to produce up to 150,000 tpa of contained copper in concentrate at an average grade of 30% for greater than 30 years. The mine site cash costs (mine/mill/SG&A) are assumed to average $1.25/lb Cu while the sustaining capital for the mine is estimated at $75M/year. These mine site operating figures will be the same for either of the investment options being evaluated.

The capital cost for development of the mine/mill is not taken into consideration, as the evaluation focuses on the trade-off between on-site cathode production and concentrate sales; the required mine/mill investment would be the same in either case. The analysis thus considers the capital and operating costs of either:

(1) Concentrate pipeline, dewatering and associated port facilities; or
(2) Concentrate leach, solvent-extraction and electrowinning

Permitting timelines, which can significantly impact the project development costs for each of the above cases, are not included in this assessment.

The major capital and operating cost inputs for the concentrate pipeline option are summarized in Table 3.

Table 3 – Concentrate Pipeline Cost Assumptions

Concentrate Pipeline Option	Capital Cost	Capital Cost Factor	Operating Cost
Pipeline	$150M	$1M/km	$0.075/t ore milled
Concentrate dewatering & port facilities	$100M	$0.20/tpa CCT	$0.5/t ore milled
Total	$250M		$0.575/t ore milled

The assumptions in Table 3 were estimated based on capital cost outputs from external studies and feedback from industry engineering consultants. They are not specific to any one project, but instead are intended to represent a reasonable order of magnitude estimate.

The major capital and operating cost inputs for the concentrate leach option are summarized in Table 4.

Table 4 – Concentrate Leach Cost Estimates

Concentrate Leach Option	Capital Cost	Operating Cost
Pressure Leach Plant	$375M*	$0.15/lb Cu
Solvent Extraction & Electrowinning	-	$0.16/lb Cu
Total	$375M	$0.31/lb Cu

* Includes a $25M cost allowance for integration into existing SX/EW plant

The concentrate leach cost estimate in Table 4 was scaled from historical capital cost outputs from internal prefeasibility and feasibility level studies and feedback from engineering consultants. In addition to cost profiles presented for each case in Table 3 and Table 4, key market and commercial assumptions presented in Table 5 were assumed for the evaluation using data sourced from Wood Mackenzie metals services reports [12].

Table 5 – Market and Commercial Assumptions

Long-Term Copper Price [13]	Long-Term Smelter TC/RC [13]	Cathode Premium [3]	Ocean Freight *
$3.35/lb	$86/$0.086	$100/t	$80/t

* Assumption based on general market outlook

A comparison of the pre-tax free cash flow (FCF) from operations for the concentrate pipeline and the concentrate leach plant option is presented in Figure 2.

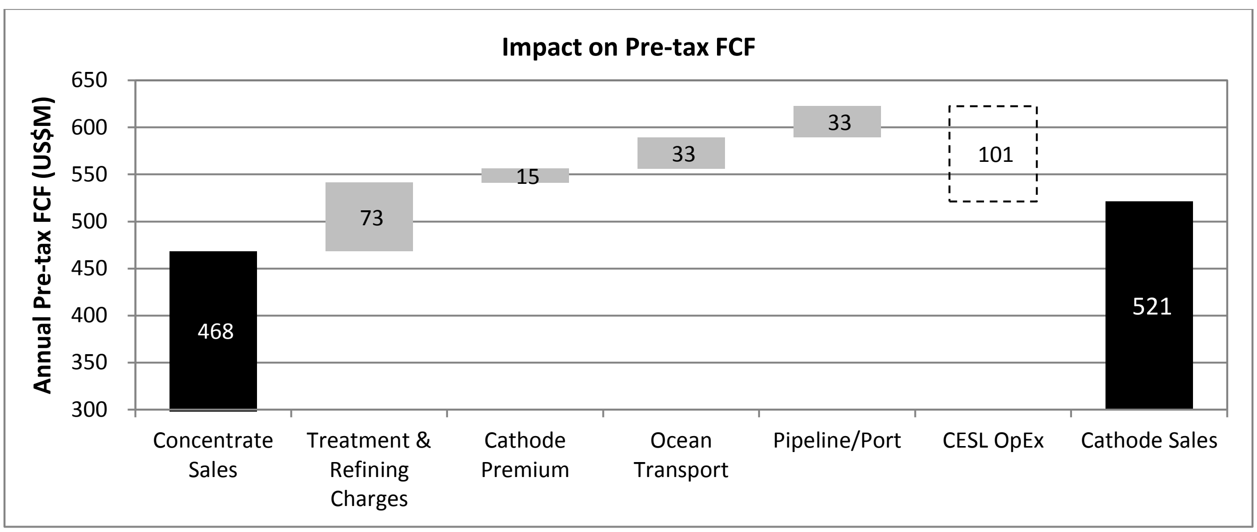

Figure 2– Pre-tax Free Cash Flow Comparison

The concentrate leach plant option, which yields market ready LME Grade A copper cathode for sale, generates an increase in annual pre-tax FCF from operations of approximately $53M as compared to the concentrate sales option. This is a favorable increase which helps protect the operation from potential cost increases in other areas of the operation such as higher mining costs, and also decreases exposure to increasingly volatile and unpredictable downstream costs, including treatment and refining charges and ocean transportation.

The operations' C1 cash costs for the concentrate pipeline option and the concentrate leach plant option are summarized in Figure 3.

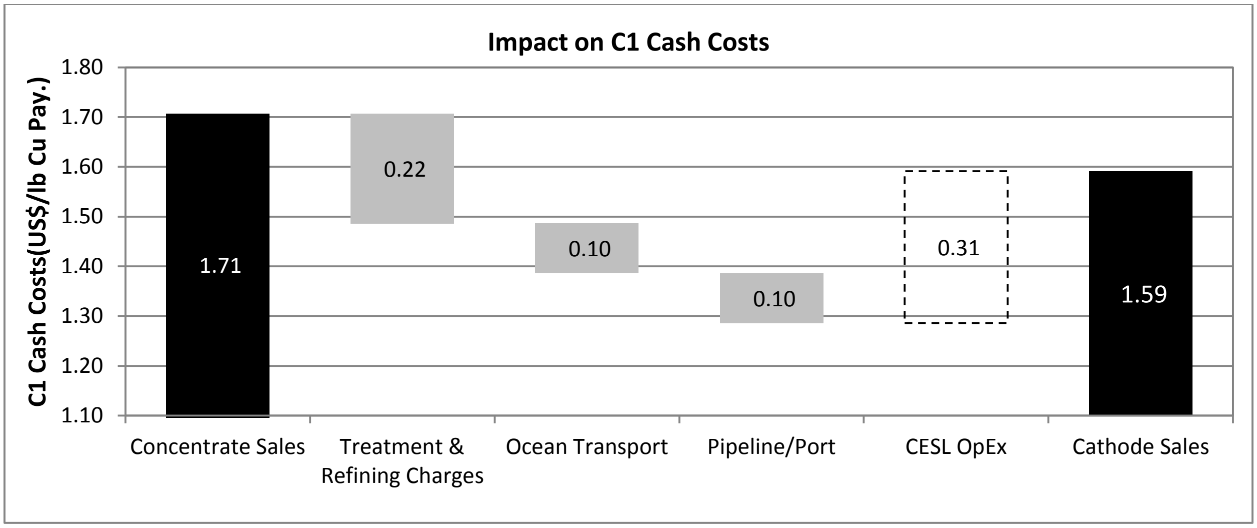

Figure 3 – C1 Cash Costs Comparison

Figure 3 illustrates the potential reduction in annual C1 cash costs achievable through the application of on-site concentrate leaching. After accounting for the operating costs associated with the concentrate leach plant, the mine operation saves approximately 12¢/lb Cu on downstream costs, equivalent to $39M/year. This results in a C1 cash cost of $1.59/lb Cu payable for on-site concentrate leaching vs. $1.71/lb Cu payable for a concentrate pipeline.

From the above assessments of pre-tax operating free cash flow and C1 cash costs, investing in the integration of a concentrate leach plant with existing solvent extraction and electrowinning infrastructure to produce cathode versus the construction of a concentrate pipeline to deliver concentrate to overseas markets is a favorable option based on the assumptions provided earlier in the paper. The economics of a concentrate leach plant investment net of the capital savings over that required to construct the concentrate pipeline is summarized in Table 6.

Table 6 - Economic Returns on Net Capital Invested for Concentrate Leach Plant

Financial Summary	Value
Capital Invested (leach)	$375M
Capital Savings (pipeline & facilities)	$250M
Net Capital Investment	$125M
Net Present Value (8%)	$410M
IRR	36.1%
Simple Payback	2.3 years

The financial metrics presented in Table 6, including a positive NPV, attractive IRR, and relatively short payback, further support the decision for the installation of a concentrate leach plant over the construction of a concentrate pipeline.

The installation of a concentrate leach plant has other potential value creating benefits over traditional concentrate sales that should be taken into consideration. Some of these include:

- Establishing several new highly skilled jobs in-country through the construction of a concentrate leach plant while sustaining several skilled jobs by maintaining the existing SX/EW operations for the duration of the project.

- Increased local employment will strengthen the local economy and add to the government tax revenue to help build additional capacity in country.

- Enhanced worker health and safety conditions through the application of a new mine-to-metal hydrometallurgical solution with no hazardous gaseous emissions or fugitive dusts as seen in some pyrometallurgical facilities.

- Delivery of value added copper cathode to market sooner while improving overall product stewardship and environmental performance through the processing of concentrates including those with elevated heavy-metals (such as Sb, As, Cd, Hg) and management of waste materials at a single industrial site.

- Reduced demand on fresh water usage through the flexible use of seawater, brine or gray water as process water in the copper leaching plant.

CONCLUSION

Teck’s CESL Copper Process has been extensively tested on a variety of copper concentrates and is being evaluated for commercialization at a large industrial scale at several greenfield and brownfield projects. The staged development path employed by Teck to advance the technology will ensure projects are developed in a timely manner by mitigating risks associated with start-up including slow ramp-up periods and failure to achieve design performance (i.e. quality and/or throughput) of future commercial operations.

The conceptual case study presented in this paper supports the installation of a concentrate leach plant over the construction of a concentrate pipeline. The integration of CESL copper leaching technology with existing solvent extraction and electrowinning infrastructure for on-site metal production of cathode represents a capital efficient alternative to conventional concentrate sales that can increase operating cash flow from operations while providing several additional value creating benefits to the operation.

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