CESL COPPER PROCESS – AN ECONOMIC ALTERNATIVE TO SMELTING

Glenn Barr, Jennifer Defreyne, Keith Mayhew
CESL Engineering

ABSTRACT

Cominco Engineering Services Ltd (CESL), a subsidiary of Teck Cominco Metals Ltd, has developed proprietary hydrometallurgical processes for the treatment of nickel, copper and copper-gold concentrates. Besides successfully treating standard concentrates, the processes have a demonstrated capability to refine "dirty" concentrates containing fluoride, arsenic, bismuth and other impurity elements that pose serious challenges in conventional smelting.

This paper will give a brief overview of the CESL Copper Process chemistry and flowsheet configuration, including metallurgical results from recent pilot plant testwork. Further to that, CESL on-site processing costs will be compared to commercial sale of concentrate via two separate case studies.

BACKGROUND

History of the CESL Process

CESL began developing the CESL Process in 1992, with the express purpose of developing a new hydrometallurgical process to convert copper sulphide concentrates to copper metal using known technologies in an innovative fashion.

The successful results of the initial bench scale tests initiated the design and construction of a fully integrated pilot plant facility, which commenced operation in 1994. The pilot plant, capable of producing 13 tpa (or 36 kgpd) of copper cathode, conducted testwork on copper sulphide concentrates throughout 1994 and 1995. Operation of the pilot plant confirmed the metallurgy of the process, but left many engineering questions unanswered.

In 1996, CESL designed and built a demonstration scale plant capable of producing 730 tpa (or 2 tpd) of copper cathode. The purpose of the plant was to minimize the scale-up risk by obtaining accurate engineering and design data from small commercial equipment. From 1997 to 2000, the demonstration plant tested several copper concentrates of varying grades.

As the process matured into a viable alternative to traditional pyrometallurgy, CESL began customized testing of the process to treat an assortment of concentrate grades and mineralogies. Testwork was performed on copper–zinc and copper-nickel-cobalt concentrates at the pilot plant in 1996 and again in 2001-2002. In 2002 through 2005, pilot-scale testwork conducted by CESL indicated that gold was recoverable through cyanidation of the copper plant residue. Preliminary results have shown exceptional gold extraction and minimal cyanide consumption.

Applications of the CESL Process

The objective of the CESL Process development was to provide an economically attractive alternative to traditional copper smelting. The CESL process:

- is capable of treating a variety of sulphide concentrates;
- allows the economic treatment of low-grade, bulk concentrates;
- has demonstrated capability to refine high impurity concentrates;
- uses only known process unit operations;
- produces environmentally stable residues;
- generates no effluents or sulphur dioxide emissions;
- reduces shipping costs; and
- offers much lower capital cost than smelting.

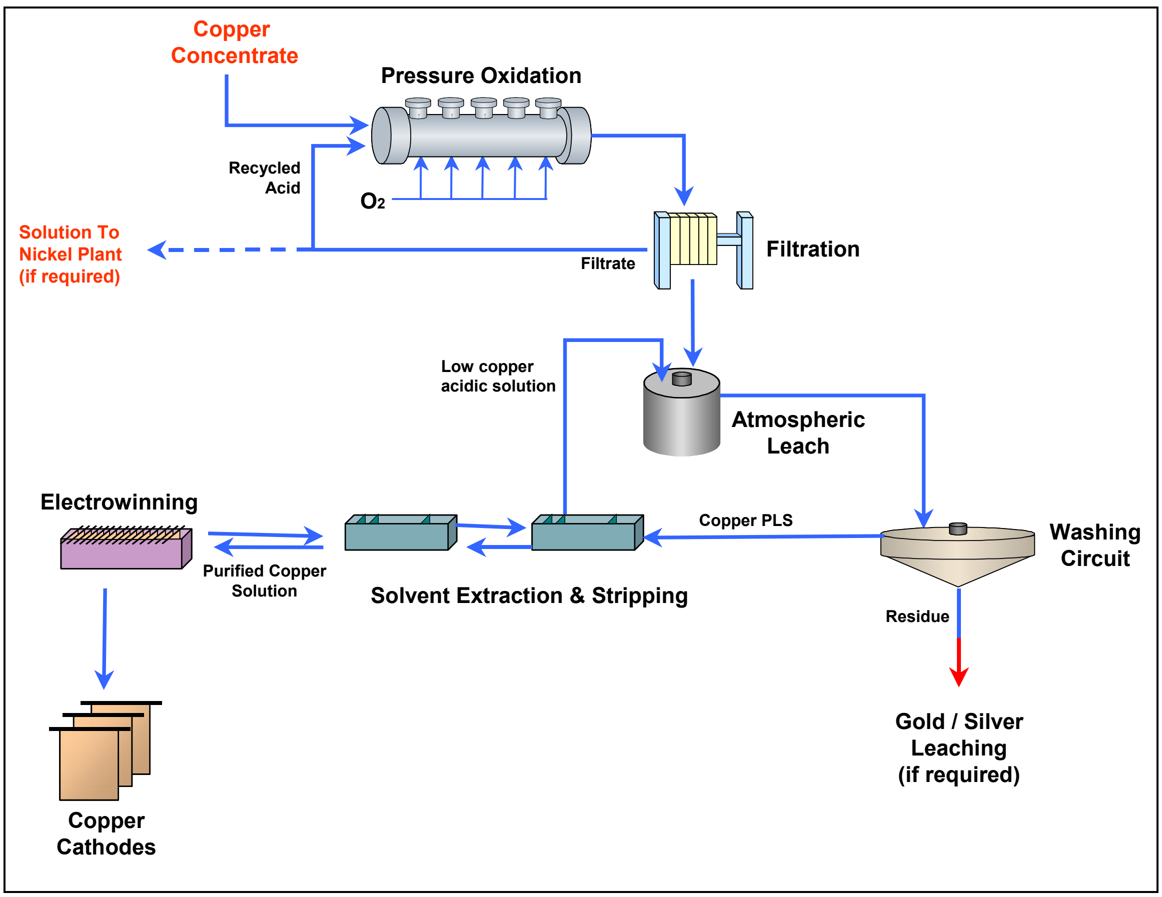
To minimize the scale-up risk, CESL uses only known technologies and common reagents in its hydrometallurgical process. Piloting occurs as an integrated process in equipment that can be easily scaled up using fundamental principles.

PROCESS DESCRIPTION

The CESL Process (Figure 1) involves oxidation of sulphide concentrates at elevated pressure and temperature in the presence of catalytic chloride ions. This is performed within an autoclave. The oxidized copper forms basic copper sulphate (BCS), which is an acid soluble solid. Copper from the BCS is subsequently leached under mildly acidic conditions at atmospheric pressure and temperature. Copper is recovered from solution by conventional solvent extraction and electrowinning.

The CESL Process can also be used to recover gold, silver, nickel, cobalt and zinc metal values from concentrates. Gold and silver have been successfully recovered during demonstration phase operations, with nickel, cobalt and zinc electrowon during pilot phase operations.

Figure 1 – CESL Process Basic Flowsheet



Process Details

Concentrate Re-grind

A light regrind of the concentrate is required to increase the surface area of the copper sulphide minerals, thereby improving the autoclave reaction kinetics. The ground slurry is thickened to 68% solids and pumped to the pressure oxidation circuit as feed for the autoclave.

Pressure Oxidation (PO)

The concentrate slurry is fed to the autoclave, where it is combined with oxygen and recycled process liquor containing 12 g/L chloride and acid. Within the autoclave, the copper sulphide minerals are oxidized to form basic copper sulphate, hematite and elemental sulphur. The oxidation reactions of copper sulphide minerals are shown below:

$$\text{Chalcopyrite: } 12CuFeS_2 + 15O_2 + 4H_2O + 4H_2SO_4 \rightarrow 4CuSO_4{\cdot}2Cu(OH)_2 + 6Fe_2O_3 + 24S^{\circ}$$

$$\text{Bornite: } 3Cu_5FeS_4 + {}^{39}/_{4}O_2 + 5H_2O + 5H_2SO_4 \rightarrow 5[CuSO_4{\cdot}2Cu(OH)_2] + {}^{3}/_{2}Fe_2O_3 + 12S^{\circ}$$

$$\text{Chalcocite: } 3Cu_2S + 3O_2 + 2H_2O + 2H_2SO_4 \rightarrow 2[CuSO_4{\cdot}2Cu(OH)_2] + 3S^{\circ}$$

The autoclave slurry is flash discharged, thickened and filtered. The thickener overflow is recycled back to the autoclave. The filter cake is repulped in raffinate and processed through atmospheric leach.

Atmospheric Leach (AL)

The PO residue is repulped in acidic SX raffinate and is pumped to the AL circuit. Additional SX raffinate is added in the reactors to maintain a pH of 1.6 – 1.8. Total retention time in the reactors is one hour.

The final reactor slurry is washed in a 5-stage counter current decantation (CCD) circuit to wash the soluble copper from the leach residue. The overflow from the first thickener (PLS) is fed to SX. Wash water to the CCD circuit is a combination of plant water and recycled neutralized raffinate.

In the absence of precious metals, the final washed residue from the CCD circuit is sent to a tailings pond. If precious metals are present in the concentrate, the washed residue is sent to the Gold Plant for further treatment.

Neutralization

Sulphate enters the plant liquor through sulphur oxidation in the autoclave and through sulphuric acid addition in electrowinning. To maintain a sulphate balance, an equivalent quantity of sulphate must be removed from the plant liquor. This is accomplished through acid neutralization by limestone.

Solvent Extraction (SX)

The CESL Process utilizes an organic mixture of 40% v/v extractant (LIX 973N®) and 60% v/v kerosene diluent (conosol 170E) to selectively extract copper from the PLS stream. A typical configuration for the main solvent extraction circuit is 2 stages of extraction, a single organic wash stage and 2 stages of stripping. A secondary solvent extraction circuit (2-stages of extraction) is used to generate wash water from neutralized primary raffinate. The raffinate from secondary SX is recycled to the CCD circuit.

Electrowinning (EW)

Pregnant electrolyte (PE) from SX is fed to a conventional copper electrowinning circuit for plating to LME Grade A cathode.

RECENT PILOT PLANT RESULTS

A discussion of recent CESL Copper Process pilot plant results is presented in the following sections. The CESL pilot plant operates continuously, with each of the unit operations integrated with the rest of the plant.

Metallurgical results from two different concentrates, labeled concentrate A and B, are compared. The major difference between the two concentrates is the copper and pyrite mineralogical compositions. Due to confidentiality agreements, the name of the concentrates discussed in the following section has not been disclosed.

Feed Material

Table 1 presents the composition of the copper sulphide concentrates processed at the pilot plant.

Table 1 - Concentrate Composition

Concentrate	Cu (%)	Fe (%)	S (%)
A	24.4	30.0	32.9
B	28.5	29.9	26.4

Using the concentrate compositions and mineralogical reports, reconciled mineralogies were determined. Table 2 presents the estimated mineralogy for the concentrates.

Table 2 - Reconciled Concentrate Mineralogy

Concentrate	Chalcopyrite $CuFeS_2$	Pyrite FeS_2	Bornite Cu_5FeS_4	Chalcocite Cu_2S	Covellite CuS	Magnetite Fe_3O_4	Silicates Si
A	70	17	-	-	0.5	-	11
B	73	0.5	4.0	0.5	-	10	12

Operating Parameters and Key Metallurgical Results

The operating parameters that are used in the pressure oxidation circuit for both of the concentrates are presented in the following table.

Table 3 Operating Parameters

Operating Parameter	Concentrate A	Concentrate B
Autoclave Retention Time	75 min	60 min
Autoclave Solids Density	16% (by weight)	18%
Operating Temperature	150°C	150°C
Operating Pressure	1380 kPag (200 psig)	1380 kPag
Oxygen Over-pressure	1000 kPag (146 psig)	1000 kPag
Vapour Space O_2	85% (dry)	85%
Feed Chloride Tenor	12 g/L	12 g/L

Table 4 presents the final residue compositions. The primary constituents of the final residue are hematite, elemental sulphur and gangue material.

Table 4 – Final Residue Composition

Concentrate	Cu (%)	Fe (%)	S (%)	S° (%)	S^{2-} (%)	S as SO4 (%)
A	1.20	33.5	28.6	24.0	3.5	1.1
B	1.51	36.6	29.0	26.2	1.3	1.5

The metallurgical results for the operations are presented in the following table. Overall copper extraction was 95.9% for concentrate A and 95.6% for concentrate B. Conversion of sulphur to sulphate was 20% with concentrate A and 7% with concentrate B. Sulphur oxidation was lower with concentrate B due to the decreased pyrite content in the feed.

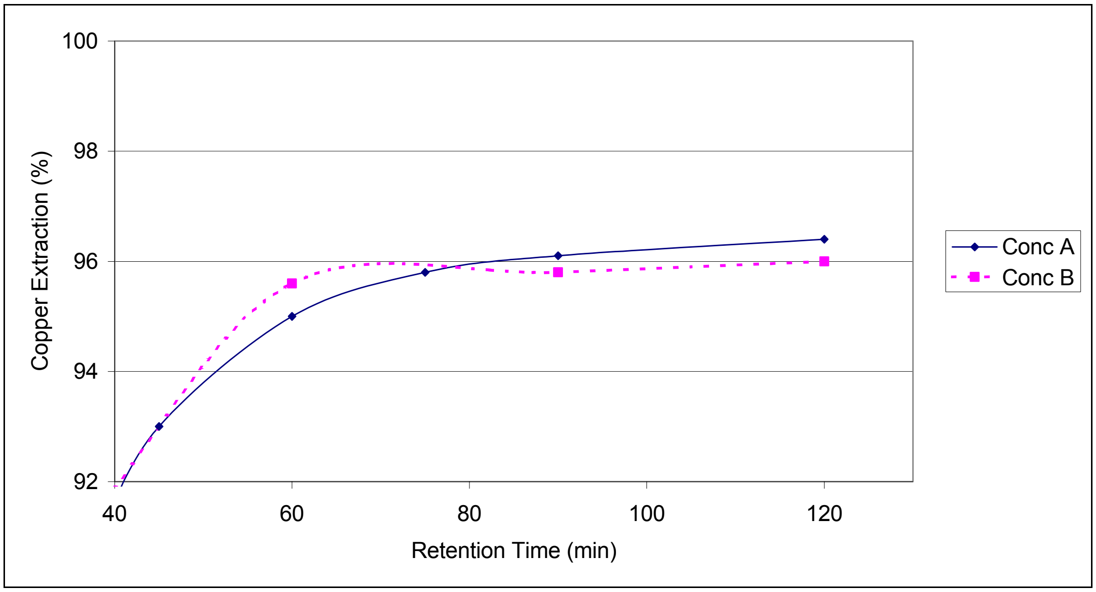
Table 5 - Key Metallurgical Results

Metallurgical Result	Concentrate A	Concentrate B
Copper Extraction	95.9%	95.6%
Overall Copper Recovery to Cathode	95.6%	95.1%
% Copper in Residue	1.20%	1.50%
% Mass Loss, Concentrate to Residue	16%	16%
O_2 Ratio – Gross	0.37	-
O_2 Ratio – Net	0.34	0.21
Sulphur Oxidation	20%	7%

Autoclave Performance

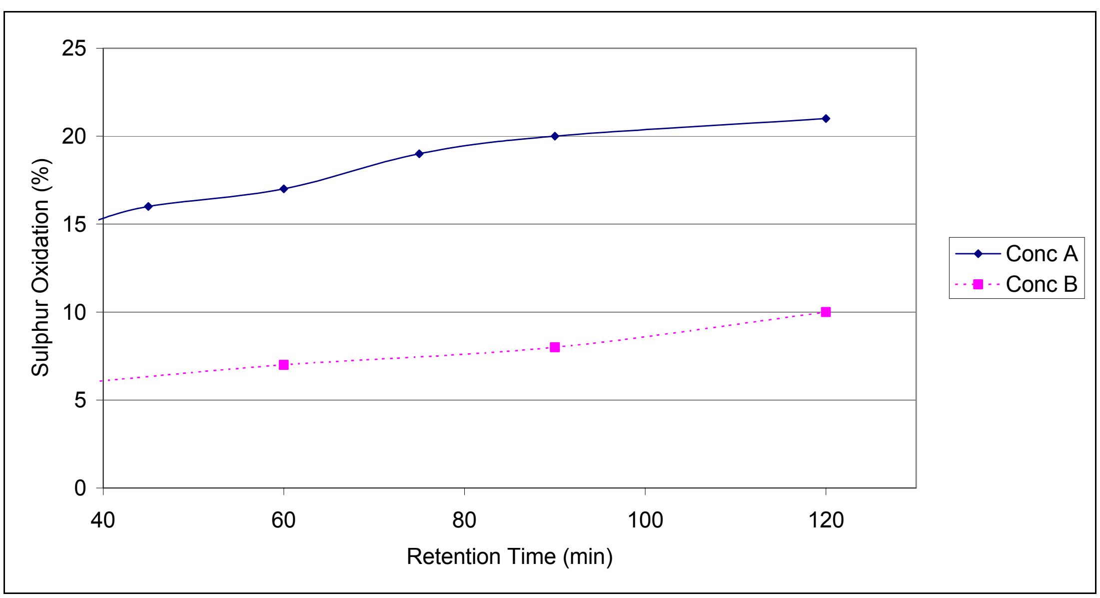
During the pilot plant operations, the autoclave operated at varying retention times. Increased retention time led to higher copper extraction for both concentrates, with minimal copper extraction occurring at retention times in excess of 60 minutes. Figure 2 summarizes the findings.

Figure 2 - Autoclave Copper Extraction Results at Varying Retention Times



The amount of sulphur oxidation that occurs is also a function of retention time, with increased oxidation occurring at increasing retention times. Sulphur oxidation is higher for concentrate A than B due to the high pyrite composition of the concentrate. Figure 3 summarizes the findings.

Figure 3 - Autoclave Sulphur Oxidation Results at Varying Retention Times



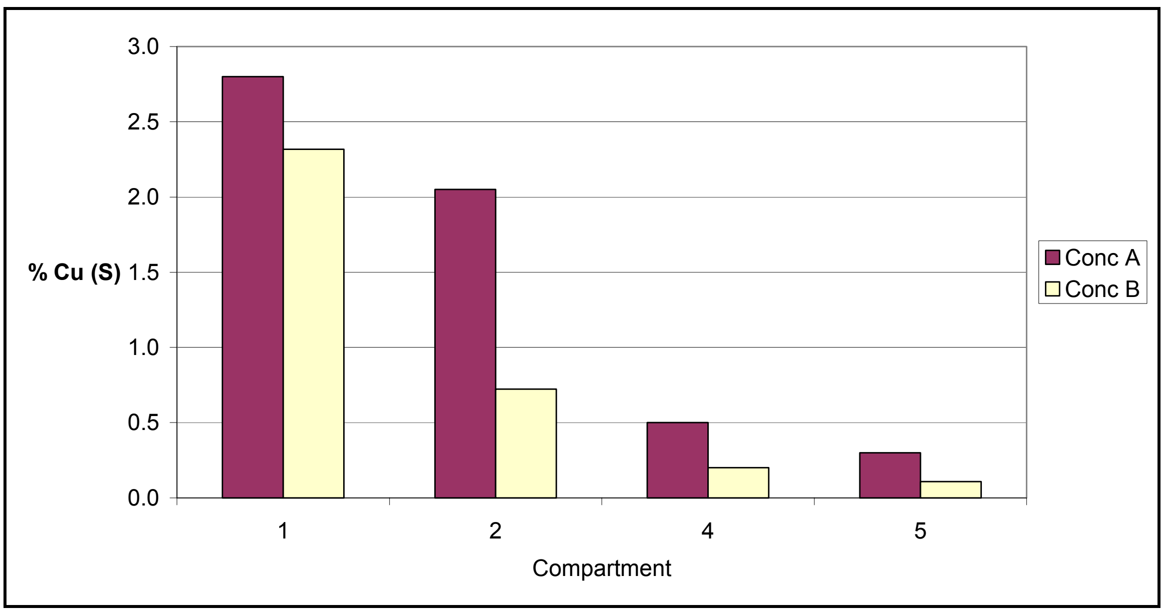
The effect of concentrate grind size feeding the autoclave was investigated during operations to determine if a finer grind would increase copper extraction. As shown in the following table, a finer grind had no measurable effect on copper extraction with concentrate A.

Table 6 – Concentrate A Results at Varying Grind Size at 75-minute Retention Time

Grind Size US Mesh	Copper in Residue %	Copper Extraction %
5% + 325	1.19	95.8
5% + 400	1.20	95.8
5% + 500	1.18	95.9

To further optimize copper extraction, compartment samples from the autoclave were taken to provide a leaching profile. The results from the compartment profiles are presented in figure 4. An analysis indicates that over 99% of the sulphide copper for either concentrate was oxidized by compartment 5.

Figure 4 – Autoclave Compartment Residue Copper Sulphide Profile



COMMERCIAL DEVELOPMENT

The CESL Process has been under development for over 10 years. Teck Cominco has continually supported the process development efforts of CESL, a wholly-owned subsidiary, during a period in which the significant capital resources were applied to the development of Teck Cominco power, gold, zinc and coal assets. The CESL process is ready for commercialization. Teck Cominco has now partnered with CVRD to assist in the commercial development of the CESL Process. CVRD has approved construction of an industrial scale 10,000 tonne-per-year plant, with start-up scheduled for mid-2007. The project is currently at the basic engineering and design phase.

It is anticipated that the 10K plant will operate for 2 years, processing chalcopyrite copper concentrate. The plant may continue to operate beyond 2 years if it is economically favourable to do so. Following a successful start-up and operation of the 10K Plant, a larger 235,000 tpa facility will be considered to process multiple concentrates.

CESL PROCESS CASE STUDIES

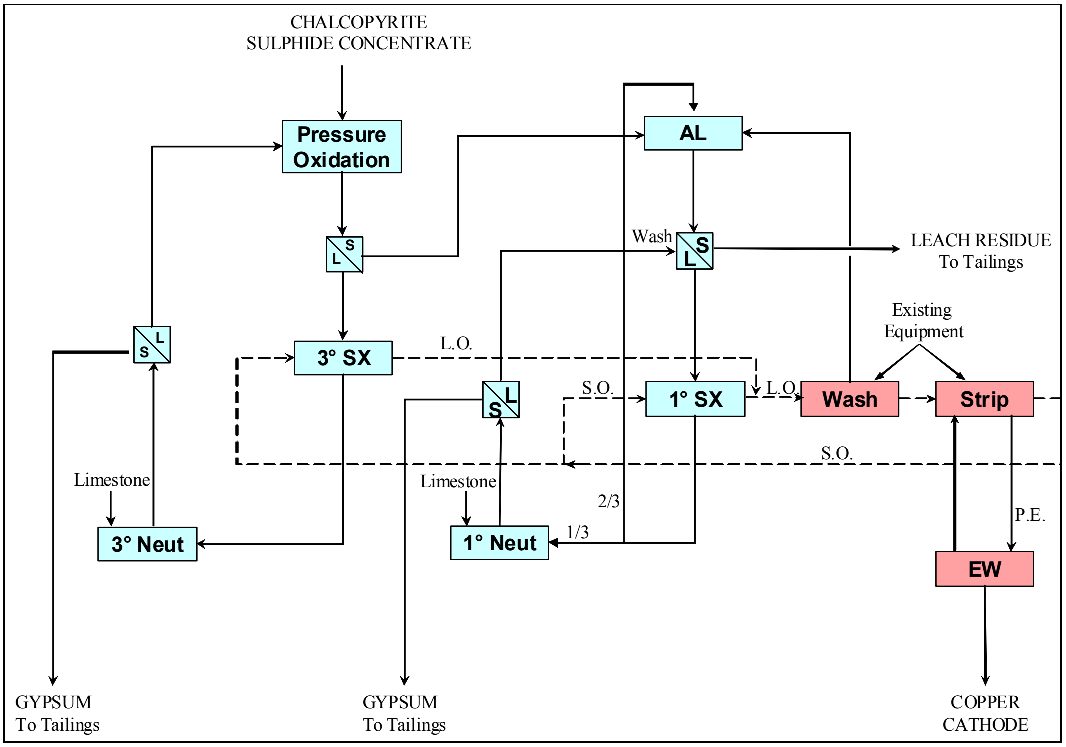
Several feasibility level cost estimates have been carried out in recent years to cost CESL Copper Plants at various capacities and locations. The following section presents two case studies where project economics are compared for building an on-site CESL Refinery versus shipping a concentrate for smelting.

Case I – Integrating a CESL Plant with Existing SX/EW Infrastructure

Many copper oxide deposits are currently processed through heap leaching the ore, with metal recovery via conventional SX/EW technology. When these oxide deposits become depleted, companies have to evaluate if treatment of the underlying sulphide ore is economical.

If it is determined that production of a sulphide concentrate is profitable, either by augmenting the existing oxide deposit or completely replacing it, the company has to determine whether to build an on-site refinery that utilizes existing SX/EW technology or if they should sell the concentrate to market for smelting. Figure 5 illustrates the integration of the CESL Process with existing SX/EW technology.

Figure 5 – Integration of a CESL Refinery with an Existing SX/EW Circuit



For the case study, the capital and operating expenditures of a 60k tpy CESL refinery are compared to shipping and downstream smelting charges for a 30% copper concentrate. The following assumptions were used in constructing this model:

- A capital expenditure of US$75 million was allotted for the construction of a new CESL refinery where existing SX/EW capacity is in place. This cost includes: building, engineering, procurement, owners costs and an on-site oxygen plant;
- Annual operating expenditures for the CESL Plant equates to US$19 million or US$0.144/ lb Cu:

Table 7 – Operating Cost of CESL Plant

Cost Element	Operating Cost US cents / lb Cu	Annual Operating Cost US$ / annum
General and Administration	1.0	$1.3 M
Labour	2.7	$3.5 M
Utilities	5.2	$6.9 M
Reagents and Consumables	2.3	$3.0 M
Maintenance	1.9	$2.6 M
Sub Total	13.1	$17 M
Contingency	1.3	$1.7 M
Total Cost	14.4	$19 M

- Copper price of US$0.90/lb;
- Smelting Costs:

Table 8 – Downstream Costs for Cu Concentrates

		Treatment Cost US$ / lb Cu	Annual Cost US$ /annum
TC/RC	$85/t con & $0.085/lb Cu	$0.214	$28 M
Freight	$60 / t	$0.091	$12 M
Total	-	$0.305	$40 M

A summary of project economics indicate that if a CESL refinery is built at an existing heap leach site, total revenue can be expected to increase by US$21 million per year. This is equivalent to a simple payback of 3.6 years, when considering a capital investment of US$75 million.

Table 9 – Summary of Project Economics for a 60k tpa CESL Plant

Cost Element	Treatment Cost US$ / lb Cu	Cost (US$)
TC / RC and Freight	$0.305	$40 M/yr
CESL Opex	$0.144	$19 M/yr
Net Benefit	$0.161	$21 M/yr
CESL Refinery Capital Cost	-	$75 M
Simple Payback	-	3.6 yrs

Case II –Building an on-site CESL Plant

Until recently, it has generally been an accepted process route to treat sulphide concentrates by smelting. Increasing copper prices coupled with increasing downstream costs (smelter treatment and refining charges) have caused several groups to re-examine hydrometallurgical processes.

On-site refining of concentrate via the CESL Process has several inherent advantages, including:

- Provides increased cost certainty to a project as the revenue is independent of downstream costs associated with smelting;
- Can process dirty concentrates without treatment charge penalties; and
- Economically viable to treat a low-grade concentrate as there is no freight cost.

For the case study, the capital and operating expenditures of a 100k tpy CESL refinery are compared to smelting costs for a 30% copper concentrate. The following assumptions were used in constructing this model:

- A capital expenditure of US$175 million was allotted for the construction of a new CESL refinery. This cost includes: building, engineering, procurement, owners costs and an on-site oxygen plant;
- Annual operating expenditures for the CESL Plant equates to US$26.7 million or US$0.125 / lb Cu; and
- A copper price of US$0.90/lb.

To compare on-site refining and smelting costs, figure 4 illustrates the simple payback period and annual increase in revenue of a CESL Plant versus smelting cost.

Figure 4 – Simple Payback and Increase to Revenue of a CESL Plant vs. Smelting Cost

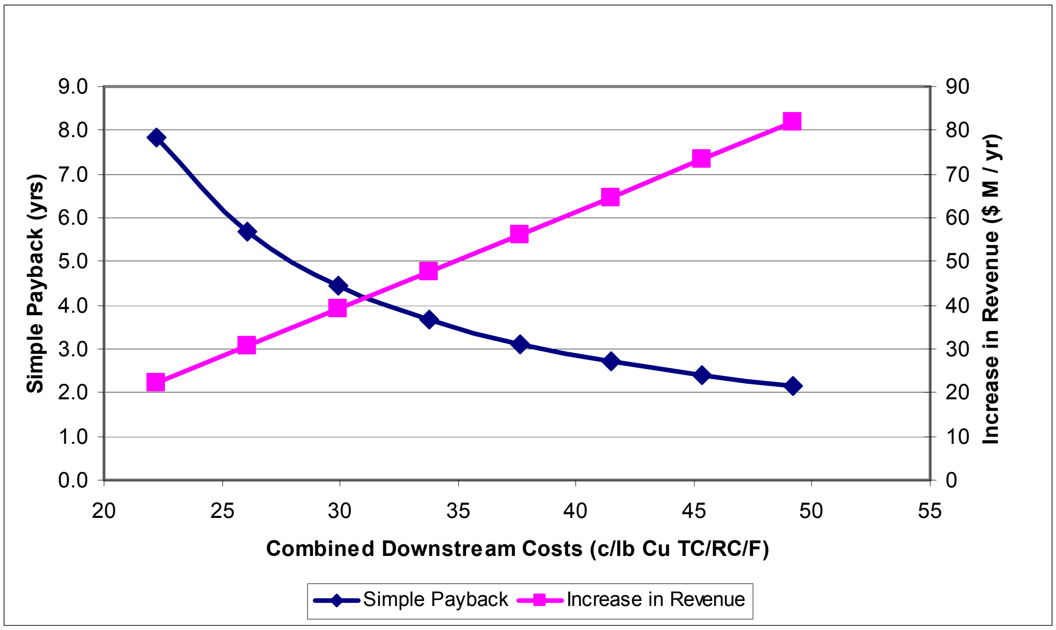


Figure 4 indicates that with increasing freight and TC/RC cost, the economics of the CESL Process become more favourable. For example, if the combined downstream smelting cost increases from 30 c/lb to 35 c/lb, a CESL Plants increase to revenue versus selling the concentrate is US$49 M per year. The increase to revenue of building a CESL Plant translates to a simple payback on capital cost of 3.6 years.

Table 10 – Project Economics for 100k tpa CESL Plant

Cost Element	Treatment Cost US$ / lb Cu	Cost (US$)
TC / RC and Freight	$0.350	$77 M/yr
CESL Opex	$0.125	$28 M/yr
Net Benefit	$0.225	$49 M/yr
CESL Refinery Capital Cost	-	$175 M
Simple Payback	-	3.6 yrs

SUMMARY

The CESL Copper Process has been thoroughly tested with a range of concentrates at both the pilot plant scale and the demonstration plant scale. Recent pilot plant campaigns have highlighted the advanced state of the CESL technology with no significant surprises during the campaigns. Copper extractions of 95-98% are consistently achieved with a variety of concentrates. Further to the testwork results, an industrial scale 10,000 tpa CESL Copper Plant has been approved and is scheduled for start-up in Brazil mid-2007.

With the CESL Process on a clear path for moving from pilot plant to production scale, the process economics for two case studies are presented.

The first case compares the cost of building a 60,000 tpa CESL Plant versus selling the concentrate for smelting at a site where existing SX/EW infrastructure is in place. Project economics indicate that by building a CESL refinery the total revenue can be increased by US$21 million per year. The capital cost of the investment is estimated at US$75 million, equivalent to a simple payback of 3.6 years.

The second case compares the cost of building a 100,000 tpa CESL Plant versus selling the concentrate for smelting where no existing refining infrastructure is in place. Project economics indicate that by building a CESL refinery, the net benefit is US$49 million per year. The capital cost of the investment is estimated at US$175 million, equivalent to a simple payback of 3.6 years. The copper production costs for both on-site refining and smelting are presented in the following table.

CESL Refinery	Smelting Total Downstream Costs
12.5 c/lb Cu	18 – 50 c/lb Cu

In both case studies, the cost comparison of a CESL refinery to existing smelting technology is favourable. With downstream smelting costs projected to remain high, a fixed, affordable refining process is an attractive option for potential companies.