CESL COPPER PROCESS - MOVING FROM PILOT PLANT TO PRODUCTION SCALE OPERATION

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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. 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.

Recently, Companhia Vale do Rio Doce (CVRD) engaged CESL to conduct pilot scale testing on a copper-gold concentrate from one of several large CVRD ore bodies in the Carajas region of Brazil. The pilot plant operated from October 2003 until February of 2004 as an integrated unit to allow each operation to reach equilibrium and to ascertain the process metallurgy. The purpose of the pilot plant was to gather design and engineering data for a final feasibility study now being conducted by CVRD for the construction of an industrial scale CESL plant. The proposed plant will be a small production scale operation (10k tpa copper cathode) intended as an intermediate step to the larger 235k tpa CVRD project for which CESL completed a major testwork campaign in 1999-2000.

This paper will give a brief overview of the final CESL flowsheet configuration and key operating results from the pilot plant testwork. The commercial development plan for the project will be presented, with preliminary capital and operating cost estimates.

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 instigated the design and construction of a fully integrated pilot plant facility, which commenced operation in 1994. The pilot plant, capable of producing 13 tpa 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 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 different 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 2003, 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 environmentally sound and 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.

Background of the CESL/CVRD Projects

CVRD is considering the application of the CESL Process to several undeveloped copper deposits in the Carajas region of Brazil, specifically the Alemão and Salobo properties. CVRD and CESL worked together extensively in 1999 -2000 to develop a process for the Salobo project, which is a predominantly bornite concentrate. The testwork was performed at both the CESL pilot and demonstration plants. Although the project was metallurgically successful, there was still concern about the technical risks associated with a new hydrometallurgical process. To minimize these risks, CVRD has decided to construct a small-scale production plant (10K tpa copper) to verify the process and serve as an intermediate step to a larger commercial application. The two companies agreed to undertake another pilot plant operation in October 2003 using chalcopyrite concentrate to further demonstrate the CESL Process. The purpose of the testwork was threefold:

- to develop a hydrometallurgical flowsheet for copper recovery;
- to gather data for a feasibility study and eventually plant design and construction of the small-scale production plant, and
- to construct and verify an accurate metallurgical model.

A feasibility study for the small-scale production plant is currently underway. The feed to the proposed plant is scheduled to be a chalcopyrite concentrate initially, followed by a bornite concentrate after successful start-up.

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.

Process Details

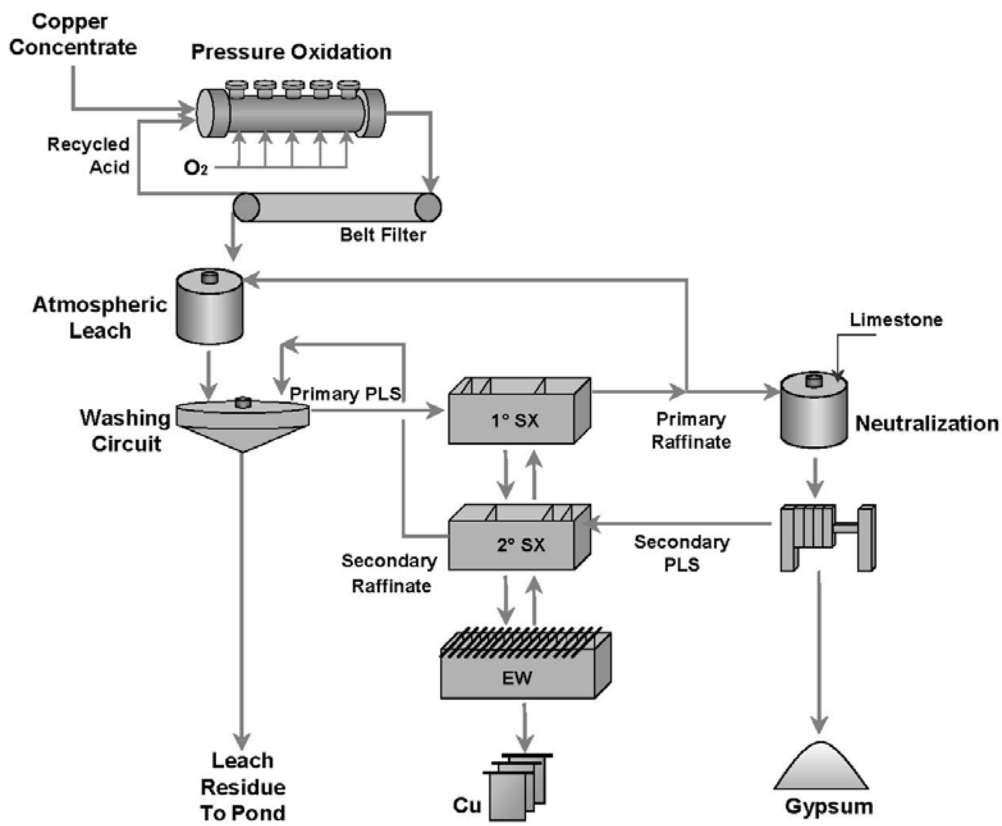
Concentrate Re-grind

A fine grind 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. There is very little sulphur oxidation to sulphate (~6-7%). The autoclave slurry is flash discharged, thickened and filtered on a vacuum belt filter. The thickener overflow is recycled back to the autoclave, while the filter cake is repulped in raffinate and processed through atmospheric leach.

Figure 1 – CESL Process Basic Flowsheet



Atmospheric Leach (AL)

The washed 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. 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. The final washed leached residue contains the precious metals from the concentrate and will be stored in a lined pond for future treatment by CVRD.

Wash water to the CCD circuit is a combination of plant water and recycled neutralized raffinate.

Neutralization

Sulphate enters the plant liquor through a small amount of 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 occurs by limestone neutralization.

Impurity Precipitation

A small impurity bleed circuit uses lime at a pH of 8 – 9 to precipitate impurity metals as hydroxides which will be stored separately from the leach residue.

Solvent Extraction (SX)

The configuration of the main solvent extraction circuit is 2 stages of extraction, 2 stages stripping and a single wash stage. The raffinate, which is not required for atmospheric leaching or for sulphate in the autoclave, is neutralized to pH 1.8 and the remaining copper is removed by a secondary extraction stage. The raffinate from secondary SX is recycled to the CCD circuit as wash water.

Electrowinning (EW)

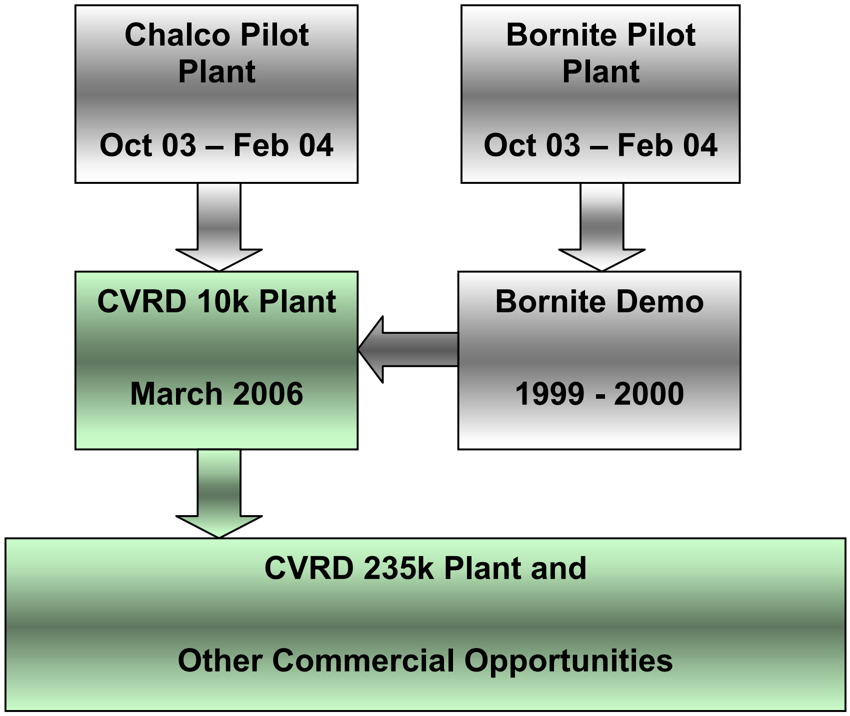
Pregnant electrolyte (PE) from SX is fed to conventional copper electrowinning for plating to cathode.

COMMERCIAL DEVELOPMENT PLAN

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. With the current agreement between CVRD and CESL, it is anticipated that CESL's time for commercialization has arrived (Figure 2).

The pilot plant and the demonstration plant testwork were completed for CVRD bornite concentrate in 1999-2000 and, more recently, a pilot scale campaign was completed using CVRD chalcopyrite concentrate in 2003-2004. A feasibility study is currently underway with Hatch providing the engineering services.

Figure 2 – CESL Process Commercial Development Plan



It is anticipated that the 10K plant will operate for 3 years, initially processing chalcopyrite copper concentrate and subsequently bornite concentrate. The plant may continue to operate beyond 3 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 a blend of the two concentrates.

RECENT PILOT PLANT RESULTS

For the period of October 2003 through February 2004, the CESL pilot plant operated using chalcopyrite concentrate supplied by CVRD. The objective of the operating campaign was to gather process and engineering design data for use within a feasibility study and to accurately model the flowsheet metallurgy.

The campaign was separated into three distinct phases:

1. Phase 1 – Commissioning and Training. The CESL pilot plant began operating on October 13, for a two-week period of staff training and plant commissioning.

2. Phase 2 – Process Optimization. Process optimization began on October 27 and stopped on December 12th.

3. Phase 3 – Process Demonstration. The demonstration phase of the campaign began on January 12th and ended February 11th.

Feed Material

Table 1 presents the average concentrate composition for each of the campaign phases.

Table 1 - Concentrate Composition

Campaign Phase	Cu (%)	Fe (%)	S (%)	F (ppm)
Commissioning	31.6	28.0	26.6	N/A
Optimization	29.6	29.1	26.7	613
Demonstration	28.5	29.9	26.4	673

Using the concentrate composition assay and a mineralogical report, a reconciled mineralogy was calculated. Table 2 presents the calculated mineralogy for the concentrate.

Table 2 - Reconciled Concentrate Mineralogy

Chalcopyrite $CuFeS_2$	Bornite Cu_5FeS_4	Chalcocite Cu_2S	Pyrite FeS_2	Magnetite Fe_3O_4	Silicates Si	Carbonates
73	4.0	0.5	0.5	10.1	12	trace

Key Metallurgical Results

The optimization and demonstration phase of the campaign exceeded CESL's expectations. Metallurgical results were better than those obtained in the bench testwork. The key metallurgical results for the demonstration campaign are presented in Table 3.

Table 3 - Key Metallurgical Results

% Copper Extraction	96%
% Copper in Residue	1.5%
% Mass Loss, Concentrate to Residue	16%
O_2 Ratio – Gross	0.249
O_2 Ratio – Net	0.205
Sulphur Oxidation	7%

Autoclave Performance

During the development phase, the pilot plant autoclave operated at 60, 90, and 120 minute retention times. The increased retention time did not materially change the copper extraction, but did slightly increase sulphur oxidation. Table 4 summarizes the findings.

Table 4 - Autoclave Results at Varying Retention Times

Retention Time min	Copper in Leached Residue %	Copper Extraction %	Sulphur Oxidation %
60	1.51	96	5.4
90	1.49	96	6.5
120	1.42	96	8.2

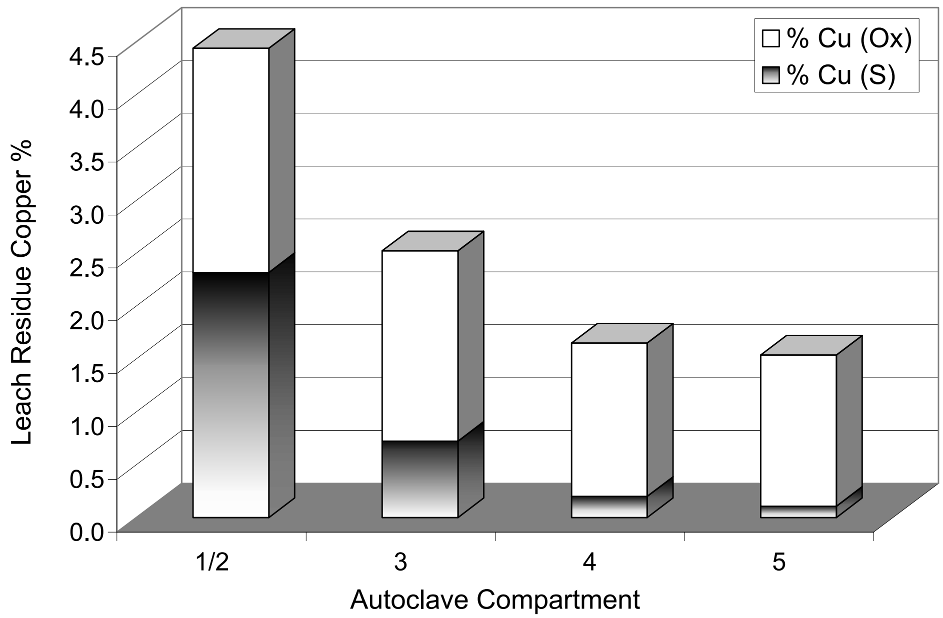
The copper remaining in the residue after pressure oxidation and atmospheric leach is a function of two parameters:

1. Some copper sulphate can become adsorbed onto the hematite. Although the copper is oxidized in the autoclave, it can only be leached through the dissolution of hematite under very high acid conditions. The copper cannot be released under the mild conditions of Atmospheric Leach.

2. Unoxidized copper sulphide is the result of incomplete reaction in the autoclave due to a number of factors, including a low chloride concentration in the acid feed, a short autoclave retention time or low oxygen pressure in the autoclave.

On several occasions, samples were taken from each autoclave compartment and analyzed for copper content (Figure 3). The samples were leached to dissolve any basic copper sulphate before analysis.

Figure 3 – Autoclave Extraction Profile at 60-minute Retention Time



The analysis indicates that 93% of copper was oxidized in C1/C2 and 99% by compartment 5 in 60 minutes.

Reagent Consumption

To minimize any risk associated with a new hydrometallurgical process, CESL uses only common reagents. These include:

- Flocculant and galactasol to aid in the settling of various slurry streams;
- Oxygen for the pressure oxidation of the copper minerals;
- LIX 973NC as the organic extractant and Conosol 170 as the diluent;
- Galactasol, a cathode-smoothing agent;
- Cobalt sulphate, which helps prevent lead sulphate formation on the anodes;
- Limestone for acid neutralization, and
- Lime for impurity removal.

Table 5 shows the plant reagent consumption with respect to concentrate consumed for the pilot plant operation.

Table 5 – Reagent Consumption During the Pilot Plant Campaign

Reagent	Consumption
Flocculant	175 g/t Conc
Galactasol	143 g/t Conc
Oxygen	231 kg/t Conc
Extractant (LIX 973NC)	0.5 L/t Conc
Diluent (Conosol 170)	6.5 L/t Conc
Cobalt Sulphate ($CoSO_4$)	0.10 kg/t Conc
Limestone	53 kg/t Conc
Lime	4.3 kg/t Conc

Impurity Deportment

Table 6 presents the extent of leaching for several elements of interest. The leaching values are expressed in g element / tonne of concentrate and are the *net* leaching values from concentrate.

Table 6 - Minor Element Leaching from Concentrate

	Mg	Al	Mn	F	Ni	Co	Cd	Zn
g/t Concentrate Composition	6100	4200	510	640	178	87	<10	120
g/t Leaching from Concentrate	200	10	100	5	27	20	4	35
% Leaching from Concentrate	3%	<1%	20%	<1%	15%	25%	--	30%

Very little impurity leaching occurs in the CESL Process, which is beneficial in that "dirty" concentrates can be easily treated and the associated costs with impurity treatment are minimized.

Mass and Energy Balance

One of the major objectives of the pilot plant campaign was to construct, improve and validate a pilot plant mass and energy balance. The balance was produced using METSIM software.

Initial input data to this model was derived from bench testwork, design basis criteria provided by CVRD and process engineering developed through prior bench, pilot and demonstration plant testwork at CESL. The model required little or no adjustment throughout the campaign as far as the key variables were concerned. Only minor adjustments were made to adequately predict the behaviour of impurities throughout the plant. The pilot plant model was then upgraded to use in the feasibility study for the small-scale production plant.

10K PRODUCTION PLANT

10k Plant Basis of Design

The basis for design of the 10k Plant is to process 38,000 tpa chalcopyrite concentrate to produce 10,000 tpa LME Grade A copper cathode. The plant will be capable of processing bornite concentrate at similar production rates.

Key operating parameters such as sulphur oxidation, copper distribution and oxygen consumption were determined during pilot plant and demonstration plant operations for bornite concentrate. These results were used to determine the key process design parameters (Table 7).

Table 7 - 10k Process Design Parameters

KEY PROCESS DESIGN PARAMETERS		
Parameter	Chalcopyrite Design	Bornite Design
% Cu in Concentrate	30.0	22.7
g/t Au in Concentrate	5.9	12
% S in Concentrate	29.1	9.8
% S Oxidation	7.1	6.1
O_2 Consumption (t/t conc)	0.237	0.100

The only significant difference between the two concentrates as far as the CESL Process in concerned, is the oxygen consumption.

10k Plant Capital Cost

A preliminary capital cost estimate was completed for the 10K plant prior to the start of the feasibility study. The estimate was US$40 million, including:

- buildings;
- installed process equipment;
- construction support;
- in-directs (engineering, procurement, project management);
- a turn-key oxygen plant;
- owner’s costs, and
- project contingency.

The estimate is in US dollars with prices prevailing in the third quarter of 2003. The majority of the plant equipment was sourced in Brazil for the purpose of the estimate (pumps, tanks, filters, thickeners, agitators, the ball mill and utility steam boilers). Only a few select pieces of process equipment were deemed to be necessary to import, such as the stripping machine and the electrolyte organic filter.

Indirect Costs are included for engineering design, procurement and project management (EPPM) up to completion of cold commissioning and hand-over of the plant to the operations staff.

10k Plant Operating Costs

Operating costs were developed for the 10K Plant (Table 8). All cost information is presented in US dollars. The operating costs presented are the average costs per annum after the plant has achieved steady-state operation.

Table 8 - 10k Operating Costs

OPERATING COSTS FOR THE 10K CESL REFINERY			
Cost Element	Annual Op Cost ($/annum)	Annual Op Cost (¢/lb Cu)	Cost Distribution
General and Administration	$220,000	1.0	4%
Labour	$1,383,000	6.3	28%
Utilities	$1,128,000	5.1	23%
Reagents and Consumables	$949,000	4.3	19%
Maintenance Supplies	$1,000,000	4.5	20%
Sub-Total	**$4,680,000**	**21.2**	**95%**
Contingency	$234,000	1.1	5%
Total Cost	**$4,914,000**	**22.3**	**100%**

Operating Labour costs were calculated based on the plant operation for 24 hours per day, 7 days per week on four continuous shift roster rotations. Labour rates for operations personnel were supplied by CVRD for this study as well as camp and catering costs (which were included in the labour cost).

In total, 120 personnel are required to run the CESL Refinery including maintenance, operations, supervision, analytical and technical support and administration.

Utility costs were estimated from a motor list that was derived for the CESL Refinery. The average cost for supply of electricity was 3.5¢ / kWh. The total power draw for the CESL Refinery will be 3.5 MW under full operating load.

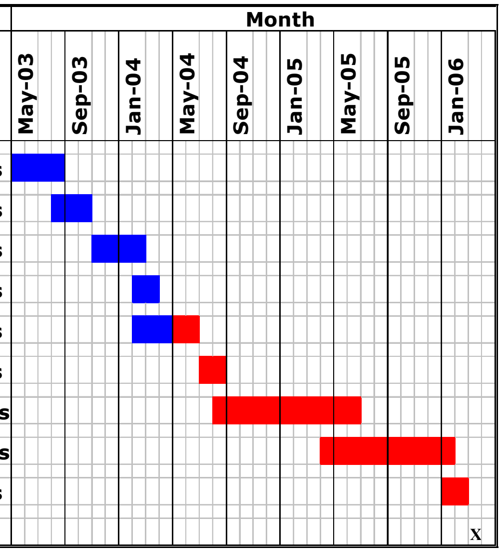
A complete list of reagents and consumables was generated from the mass and heat balance. Minor reagent consumable costs were determined based on recent quotations for reagents obtained in other CESL studies. For major reagents – sulphuric acid, limestone and quick lime – costs were provided by CVRD. A contingency of 5% of the estimated annual operating cost is allowed.

10k Plant Schedule

The project is scheduled (Figure 4) to be completed in March 2006 and is currently at the final detailed feasibility study stage.

Figure 4 – 10k Plant Schedule

Item	Start Date	End Date	Duration
Bulk Sample	**May-03**	**Aug-03**	**4 months**
Precampaign Activity	**Jul-03**	**Oct-03**	**3 months**
CESL Pilot Plant	**Nov-03**	**Feb-04**	**4 months**
Campaign Report	**Feb-04**	**Mar-04**	**2 months**
Feasibility Study	**Feb-04**	**Jun-04**	**5 months**
Project Decision	**Jul-04**	**Aug-04**	**2 months**
Detailed Engineering	**Aug-04**	**Jun-04**	**11 months**
Construction	**Apr-05**	**Jan-06**	**10 months**
Commissioning	**Jan-06**	**Feb-06**	**2 months**
Plant Operating		**1-Mar-06**	**Milestone**



COMMERCIAL PLANT OPPORTUNITIES

CESL has completed an internal study for a 235,000 tpa CESL Refinery. The capital cost was found to be US$288 million ($1,225 per annual tonne of copper). The pre-feasibility study estimate includes only the CESL Process from concentrate re-grinding through to production of copper cathode, including:

- buildings;
- installed process equipment;
- construction support;
- in-directs (engineering, procurement, project management);
- a turn-key oxygen plant;
- owner's costs, and
- project contingency.

Operating costs for the 235,000 tpa plant were found to be US$49.3 million per year or 9.5 ¢ /lb Cu.

SUMMARY

The CESL Process has a clear path for moving from pilot plant to production scale operation.

The process has been thoroughly tested for CVRD chalcopyrite and bornite concentrates at both the pilot plant scale and the demonstration plant scale. The recent pilot plant campaign highlighted the advanced state of the CESL technology. There were no significant surprises during the testwork campaign and the all required metallurgical results were obtained. The campaign data is currently being used in the final feasibility study for a 10,000 tpa plant to be built in Brazil.

The construction of a 10,000 tpa plant is scheduled to begin later this year with completion and start-up in March 2006. The capital cost is expected to be US$ 40 million and operating costs will be US 22 ¢/lb once steady state operation is achieved. The plant is expected to operate for 2 years on chalcopyrite concentrate and 1 year on bornite concentrate.

Following the successful start-up of the 10,000 tpa plant, further commercial opportunities will be explored by Teck Cominco as well as CVRD. Typical capital costs for a large commercial scale operation are US$1,125 / annual tonne copper with operating costs of 9-10 ¢/lb Cu.

CESL is continuing to develop its precious metal recovery from the leach residue. A fully-integrated pilot plant campaign is currently underway in the pilot plant in Vancouver, Canada.