ON-SITE PROCESSING VS. SALE OF COPPER CONCENTRATES

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CONTENTS

1. SUMMARY

CESL, a wholly owned subsidiary of Teck Cominco Metals, has developed a novel hydrometallurgical process for processing copper sulphide concentrates to metal. The basic concept of this process is to allow processing of concentrates on site at the mine, to minimize downstream costs, including freight on concentrate.

Although it has outstanding environmental features, the CESL Process also has to be competitive with the existing smelting industry, which has offered very attractive terms to concentrate producers over the last few years. In retrospect, that situation may be seen as an anomaly created by a number of factors, including government interference with the normal workings of the (concentrate) market, and now the market is reasserting itself. Recent increases in downstream costs have now increased the incentive for onsite processing, rather than selling the concentrate to remote smelters. This paper presents the financial analysis of an onsite refinery vs. the sale of copper concentrates.

Continued strong growth in world copper consumption over the last few years, coupled with limited reserves of heap-leachable ores (that don't require smelting) has now created a bottleneck in world smelting capacity. This has naturally resulted in rising smelting and refining charges. In addition, world freight costs have increased also, resulting in increased overall downstream costs.

Analysis of historical data for treatment and refining charges over the past 20 years indicates that there is a rough correlation of such costs with copper prices: TC/RC/PP have averaged 23 % of the copper price, although there are substantial variations from year to year.

Assuming that this relationship holds up in future, a financial analysis of a CESL Plant onsite at a mine has been calculated, in terms of return on investment (IRR). This shows that an onsite CESL plant has substantial advantages for a typical copper mine, compared to selling to a remote smelter, and itself will generate about 20 % IRR for a typical mid-sized mine, which is better than the mine itself would generate given modest longterm copper prices.

In addition to the increased return on investment, the mine is now independent of market treatment and refining costs. There are other important advantages, such as the ability to treat low grade concentrates, bulk concentrates or concentrates with penalty elements.

A number of variables that have been examined in the financial analysis including:

- copper price
- plant capacity
- concentrate Cu grade
- concentrate mineralogy leading to high S oxidation in refinery
- labour and power costs
- impurity (penalty) elements in concentrate

In most scenarios for the above variables, the onsite refinery has substantial better economics, than shipping concentrate for sale to a smelter. However, there are some situations in which an on-site refinery is not favoured, the most likely of which is the low capacity mine with small reserves but high grades of ore.

Other than these special situations, the conclusion is that onsite refining should seriously be considered for most copper mines.

2. DOWNSTREAM COSTS: OUTLOOK

The global copper markets have staged an impressive turnaround over the last couple of years, after several years of oversupply and low prices. LME copper metal inventories have been drawn down to critically low levels, causing copper prices to rise to sharply from their recent lows. Market conditions are showing no signs of slowing down and copper prices can be expected to remain high in the immediate term.This is promising news for today's current copper producers, but in order to acquire a reliable estimate for the development of future projects, the longer term outlook on copper is more important. The growth in copper consumption for the next ten years is expected to be in line with historical growth, i.e. about 3 % per year, (see Figure 1)

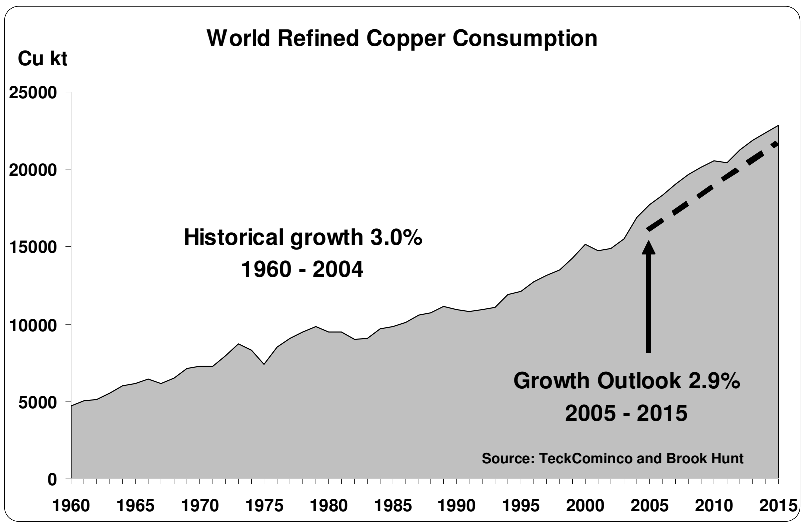

Figure 1

The source of the additional copper needed to supply this market may be different, however, than the recent past. Over the last 15 years, there has been a substantial expansion of mines using heap leaching methods for whole ore, coupled with SX-EW, which has supplied copper metal to the market without the need for smelting. This phenomenon has allowed the expansion of copper supplies without commensurate expansion of the smelting industry. Today about 25 % of new metal is supplied from this Heap Leach-SX- EW industry, with very competitive costs. However, it is popularly believed that (global) reserves of copper ores that are amenable to heap leaching are limited, with current technology. In particular, primary copper sulphides, (chalcopyrite), are not suitable for heap leaching unless a technological breakthrough can be made, and only oxides and secondary sulphides can be economically heap leached. Failing such a breakthrough on primary sulphides, and assuming that the secondary minerals are indeed limited, (this assumption has not been confirmed) further growth in the heap leaching sector is likely to be limited, and therefore insufficient to supply the continued growth in copper demand. In this situation, additional copper units in future must come from the primary ores, which are in abundance, but which require concentration, and some form of processing, such as smelting, or onsite leaching.

Under current market conditions, global smelting and refining capacity is already insufficient and downstream costs (TC/RC/PP) have increased along with the price of copper. The spot market in particular has reached historic highs of $220/t in early Q2 2005. If these market conditions are to continue, smelter capacity will remain tight, and treatment and refining charges would be expected to remain high for some time.

Therefore, a growing contribution from copper concentrates is expected to be required to meet the demand for copper metal. Figure 2 shows that by 2015, an additional 3.6 Mt/a of

Cu in concentrate is expected to be required (TeckCominco and Brook Hunt 2005). This is the background for the financial analysis of the onsite CESL refinery, presented in Section 3 below.

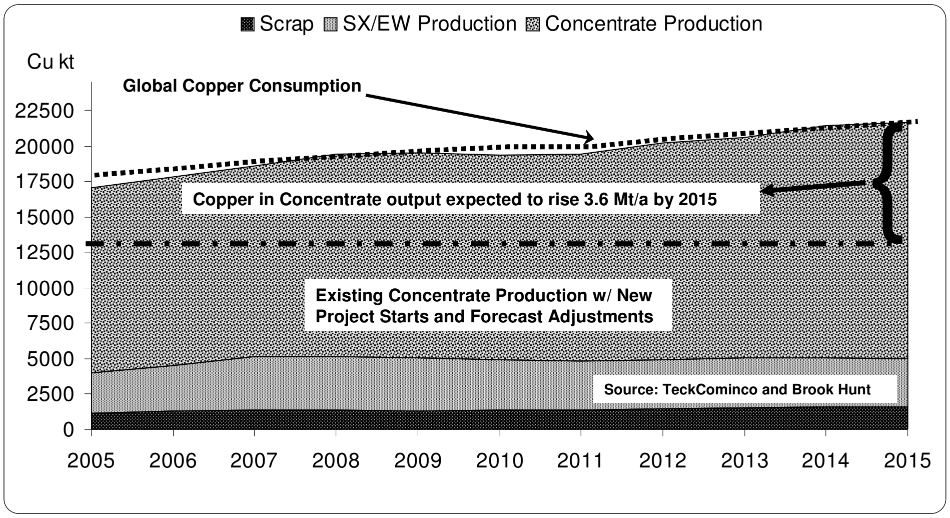

Figure 2

The pressure clearly lies on smelters to treat the increased supply of copper in concentrates, as outlined above. The direction that treatment and refining charges take will largely depend on the success of additional copper smelter capacity being brought on-line, but it clearly presents an opportunity for on-site hydrometallurgical processing of copper concentrates.

The recent recovery in copper metal prices has been followed by a dramatic rise in smelter treatment and refining charges from their historical lows of 2003.

Over the years, treatment charges have varied quite widely, since this is essentially a free market, i.e.supply of concentrate vs smelting capacity. When copper prices are low, naturally supply of concentrate dries up fairly quickly, whereas smelters keep going, thus there is a rough relationship as one might expect between copper prices and treatment charges.

Figure 3 presents the historical copper prices and TC/RCs from 1986 to present.

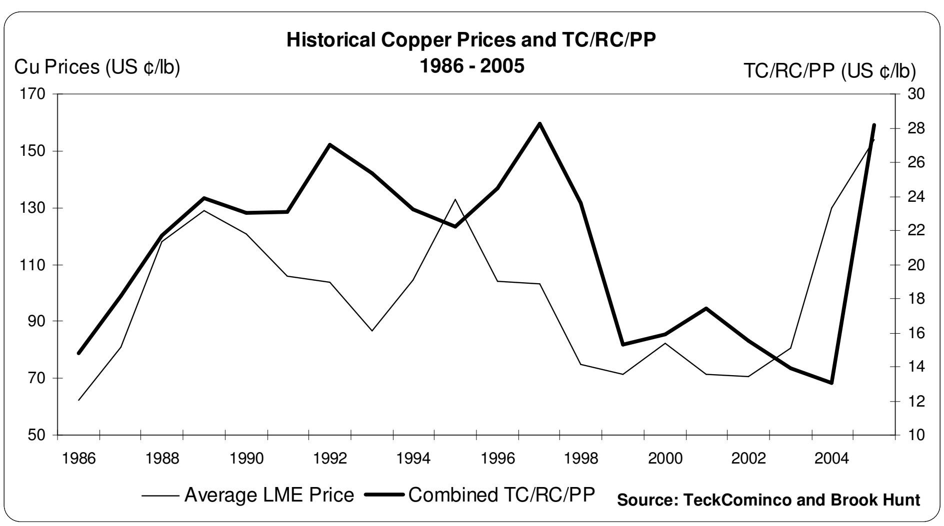

Figure 3

As one can see there is considerable variation year to year in TC/RC/PP, which does not always correlate to copper price, as in the late 90's for example. Copper prices rose and TC/RC's fell. It is believed that such anomalies have been influenced by one off events, such as the widespread introduction of SX-EW technology, and the encouragement of local smelters in some countries such as India and China, effectively by government subsidies, in the form of punitive tariffs on imported metal but not concentrates. These government initiatives provided artificial stimulation for smelter construction, which could affect the market permanently, as the subsidy itself is limited by the extent of the local market for metal, plus the resistance by local consumers, and the international trade bodies such as WTO. Therefore it should be expected that the market would eventually reassert itself, as it now appears to have done.

As a result of these anomalies, it is somewhat hard to see longterm trends. Nevertheless, when historical TC/RC/PP are plotted vs. copper price (shown in constant $ 2004), we can discern a rough statistical correlation between the two. See Figure 4.

From 1986 to 2003, the combined TC/RC/PP averaged approximately 23% of the copper price.

In early 2004, the combined TC/RC/PP reached a low of 10% of the copper price, but with the recent rise in treatment and refining charges, (at time of writing, May 2005), it has risen to about 20 % of the copper price.

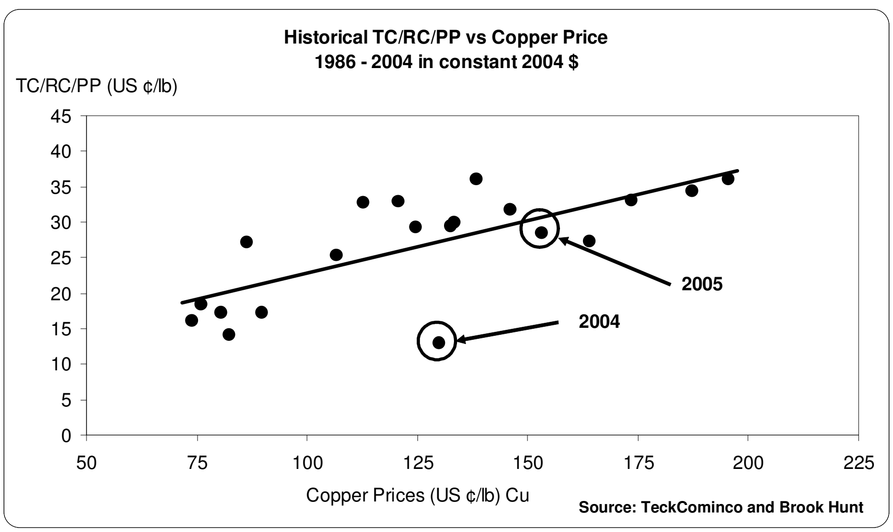

Figure 4

For the purposes of the financial analysis in the succeeding section, longterm prediction for TC/RC/PP is required. Using the above historical relationship between TC/RC/PP and copper price it is assumed that the TC/RC/PP is 23% of the copper price for the longterm average. Unless stated otherwise, this relationship is maintained throughout the financial analysis For freight costs, we used current 2005 costs of $95/t concentrate, which is current for many Canadian mines, including all components such as land freight. Adding the fixed freight to TC/RC/PP provides a total downstream cost for the financial analysis.

3. CESL PLANT: FINANCIAL ANALYSIS

This section of the paper presents the financial indicators (IRR and NPV) for a variety of project capacities, ranging from 10,000 tpa to 300,000 tpa copper cathode. Greenfield and brownfield applications are considered, where appropriate. The purpose of this paper is to demonstrate to the reader that onsite processing of concentrate is profitable and should be considered as a means of realizing a greater return on investment in a given mine.

Mine / Mill Capital and Operating Cost Estimate

In order to demonstrate that onsite refining generates a greater return on investment than shipping to smelters, capital and operating costs were required for a variety of mine and mill capacities. These costs were estimated from inhouse historical data for a variety of plant capacities, as illustrated below. These estimates were based on a hypothetical mine with the key assumptions, as outlined below in Table 3.

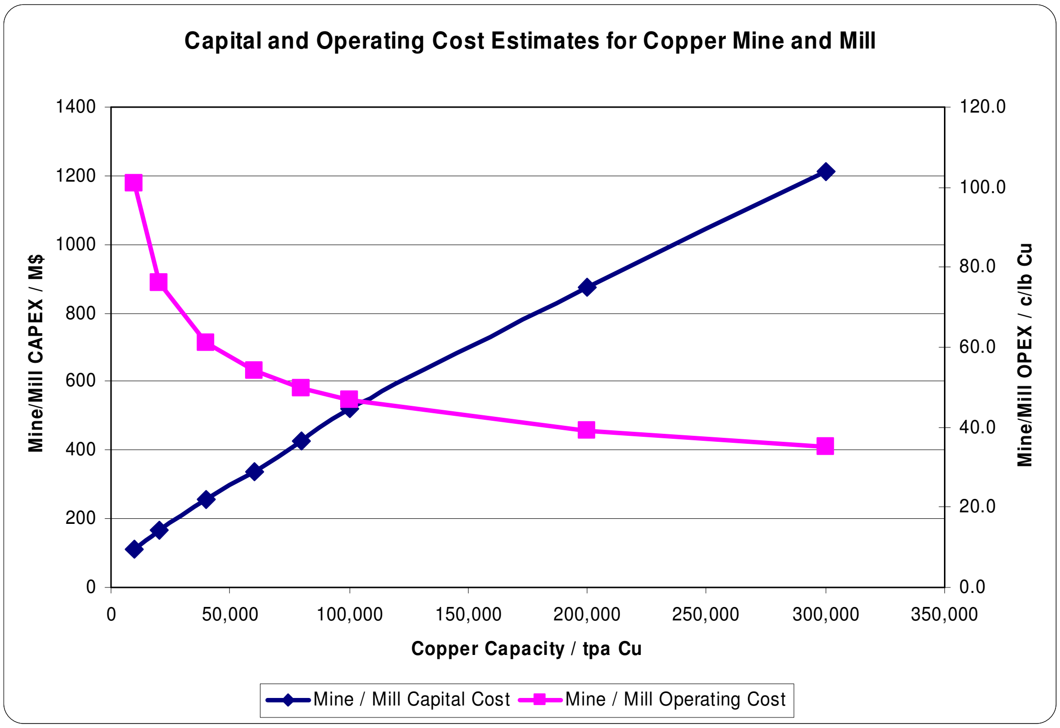

Figure 5 - Capital and Operating Cost Data for Mine/Mill Projects

Table 1 - Mine / Mill Capital and Operating Costs

Plant Capacity	tpy Cu	10,000	20,000	40,000	60,000	80,000	100,000	200,000	300,000
Mine/Mill CAPEX	US$ M	110.0	165.0	258.0	339.0	428.0	520.0	876.0	1210.5
Mine/Mill OPEX	US c/lb Cu	101.1	76.0	61.2	54.3	49.9	46.8	39.1	35.3

CESL Refinery Capital and Operating Cost Estimate

CESL refinery capital and operating cost estimates were also completed using inhouse costing experience. The figure and table below summarize these estimates.

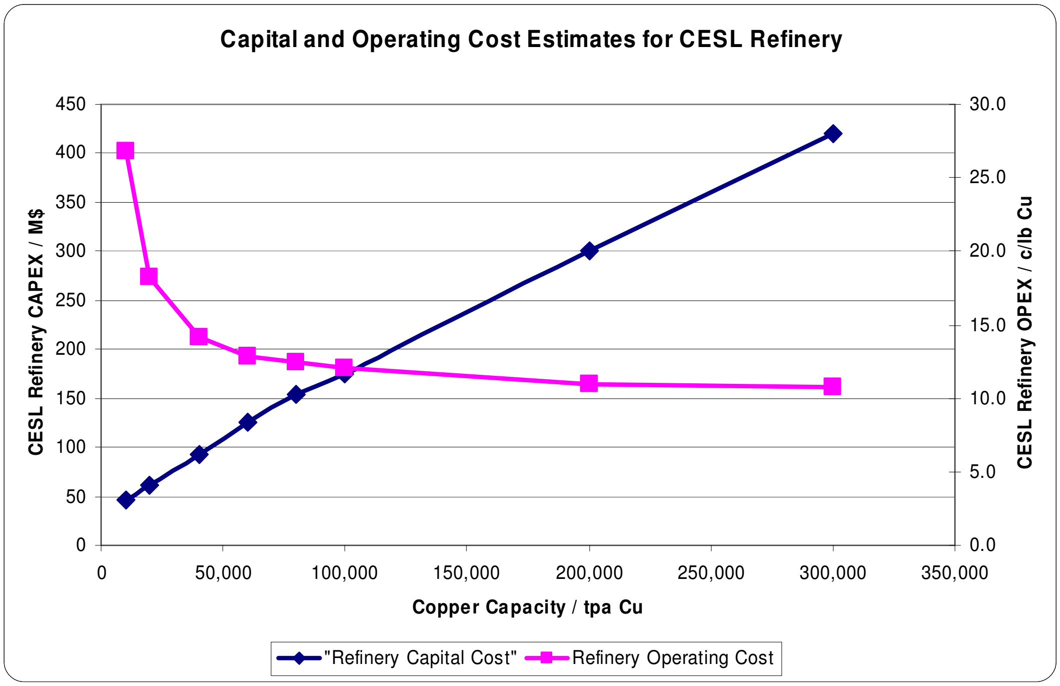

Figure 6 - Capital and Operating Cost Data for CESL Refinery Projects

Table 2 - CESL Refinery Capital and Operating Cost Estimates

Plant Capacity	tpy Cu	10,000	20,000	40,000	60,000	80,000	100,000	200,000	300,000
Refinery CAPEX	US$ M	46.0	62.0	92.0	126.0	154.0	175.0	300.0	420.0
Refinery OPEX	US c/lb Cu	26.8	18.2	14.2	12.9	12.5	12.1	11.0	10.8

Financial Review – Assumptions

One of the basic assumptions for this review was the relationship between copper price and TC/RC/PP. The long term average trend shows that TC/RC/PP is 23% of copper price. Unless stated otherwise, this relationship is maintained throughout this review. Freight has been included at 95$/t wet concentrate.

When a stand alone refinery (brownfield) number is presented, it assumes that the refinery sees a revenue equivalent to the total downstream costs (TC/RC/PP/F) being used under those conditions.

The table below summarizes other key parameters that were used during this review, and are considered the base case parameters.

Table 3 - Base Case Assumptions

Ore Grade	1.0% Copper	Smelter Payable	G – 1% / G
Ore Strip Ratio	2:1	CESL Copper Extraction	96.5%
Mill Recovery	85% to Concentrate	Cathode Premium	75 $/t
Copper Concentrate Grade	30%	Cathode Freight	75 $/t
TC / RC / PP	23% of Cu Price	CESL Sulphur Ox.	15%
PP	+/- 10% on 90c/lb Cu	IRR Range	25 year
Freight	95 $/wmt		

Preliminary Comparison

The first comparison to be made is that of project IRR versus project capacity (in tonnes of copper produced). Mine/mill versus mine/mill/refinery IRR is compared in the figure below.

As can be seen, an onsite refinery improves the project economics by approximately 8% IRR. The increase in project IRR is due to the fact that the combined downstream costs are higher than the operating plus amortization costs of the onsite refinery.

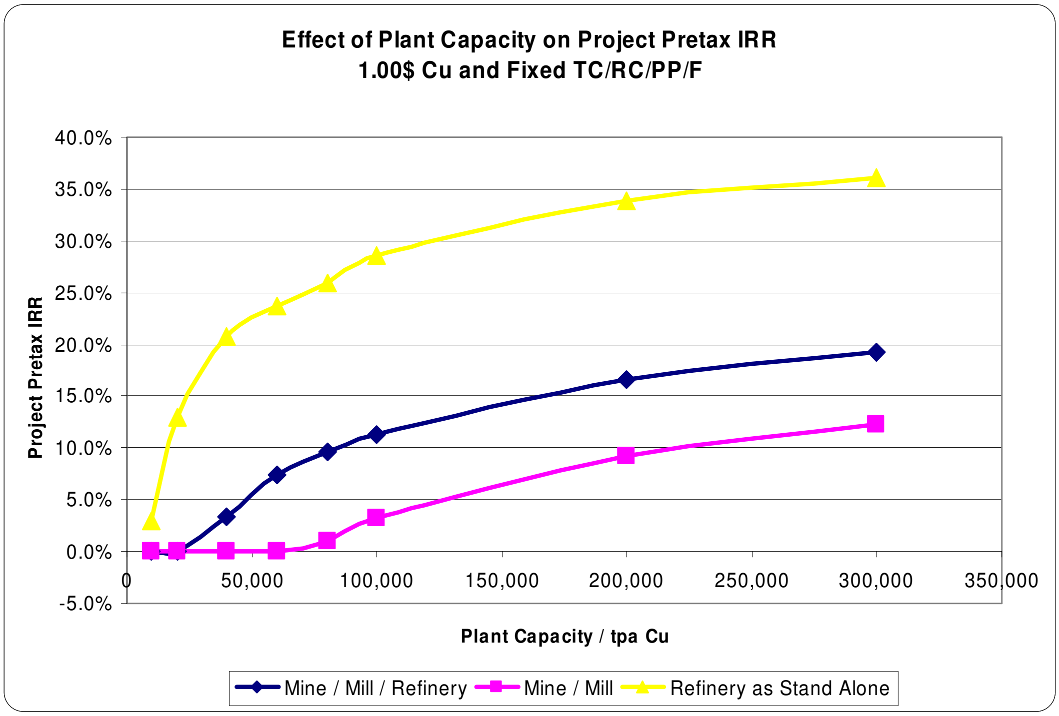

Figure 7 - Project IRR vs. Copper Capacity. Copper Price of 1.00$/lb, TC/RC/PP/F of 39.1 c/lb

Under the assumptions put forth in the preliminary comparison, the mine/mill project, alone, does not generate a positive IRR until approximately 80K tpy copper. Even at a production rate of 300,000 tpa copper, the rate of return on the mine/mill capital is shown to be just over 10%, pretax. In considering these, the assumptions quoted above should be borne in mind, particularly the ore grade, mining costs and copper price assumption. With more optimistic assumptions of course, the mine/mill project would look much better, as would the integrated plant and stand alone refinery, as well.

When an onsite CESL refinery is included in the project, the economics improve substantially. A positive IRR is realized at almost any capacity, and greater than 10% IRR (pretax) is shown at any capacity about 100K copper.

Interestingly, if one considers the construction of an onsite refinery at an existing mine/mill facility, (as opposed to a greenfield project), the economics are again attractive, with an IRR of greater than 10% shown above a 50K capacity plant. The following section reviews this scenario in a little more depth.

Required Downstream Charge for a 20% IRR CESL Refinery

At an operating mine and mill facility, where concentrate is produced and then shipped to a smelter, significant value is lost from the concentrate due to downstream costs, ie. smelting and refining charges, price participation, and freight. Historically, total downstream costs have consumed between 30% and 40% of the gross metal value of the concentrate. Reduction of these uncontrollable costs is always a focus for mine / mill complexes.

Construction of an onsite refinery eliminates the need to pay downstream costs, and provides onsite control of realization costs. Assuming a mine/mill facility is considering the application of onsite refining, we have tried to answer two questions:

i. What is the minimum capacity refinery that can be built (economically)?

ii. What is the minimal downstream charge required to justify construction of an onsite refinery, and how does it change with plant capacity?

To answer these questions, a decision was made to set an IRR of 20% (pretax) as an acceptable rate of return on refinery capital. Once that return was set, the downstream charge necessary to generate a 20% IRR on refinery capital was determined, at each of the capacities under review. The figure below displays the required downstream charge versus capacity.

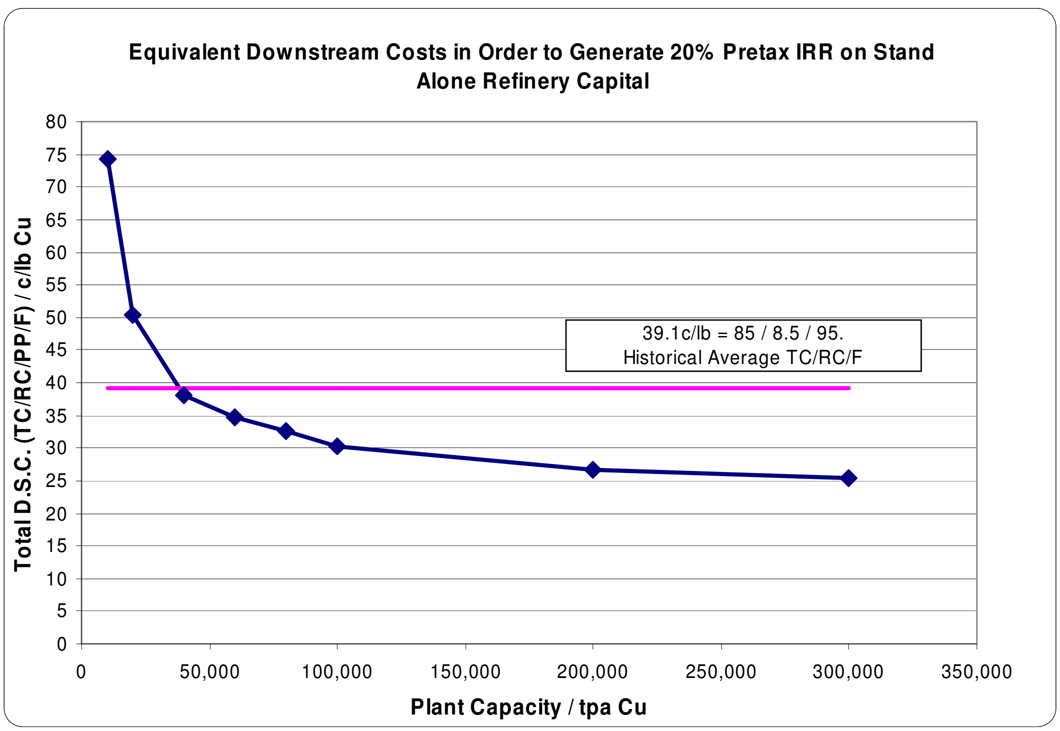

Figure 8 - Required Treatment Charge to Generate 20% Pretax IRR on Refinery Capital

The figure above shows the minimum total downstream costs necessary to justify construction of an onsite refinery. For example, at 100,000 tpa copper production, if total downstream costs are 30 c/lb copper, the savings offered by onsite refining will generate a 20% IRR on refinery capital (after refinery operating costs are considered).

This figure shows that small refineries (20K – 50K Cu /year) need to experience total downstream costs of around 40 – 50 c/lb copper in order to generate a satisfactory return on refinery investment. Above about 50,000 tpa copper, the necessary downstream charge before an onsite refinery is justified falls to between 25 and 40 c/lb Cu, which is comparable to historical total downstream costs.

Thus, the smallest economical refinery (given the assumptions discussed in this paper) would be around 50,000 tpa copper, and under standard market conditions, an onsite refinery of 50,000 tpa copper or greater should have good project economics.

The table below lists the downstream cost that is required in order to generate a 20% IRR (pretax) on refinery capital. As can be seen, at 40K copper production or higher, the onsite refinery charge is lower than the historical average total downstream costs (39.1 c/lb Cu). As the capacity of the refinery increases, so does the difference between the historical downstream cost and the onsite refinery charge, therefore indicating that greater than 20% IRR could be realized by these refineries at higher downstream cost.

Table 4 - Effective Treatment Charge to Deliver 20% Pretax IRR on Refinery Capital

Plant Capacity	tpy Cu	10K	20K	40K	60K	80K	100K	200K	300K
Onsite Refinery Charge	c/lb Cu	74.4	50.3	38.1	34.7	32.5	30.3	26.6	25.4

Therefore, in most scenarios, the onsite refinery has substantial better economics. However, there are some situations in which an on-site refinery is not favoured, such as:

- Low capacity mine, say 10K Cu with very high grade Cu ore, say 5 – 10 % Cu

- Small ore reserve for mine, leading to very short mine life, insufficient to amortize refinery, often associated with low capacity/high grade ores.

- Extended market periods where TC/RC do not correlate with Cu price, such as when governments interfere with market conditions (as happened in the late 90's

- Remote location away from electrical grid, where power is produced by generator sets, together with high oil prices

- Very high grade gold content, > 100 g/t Au in concentrate

- Very low grade concentrate, containing high % pyrite, (over 50 %)

Case Study - 100,000 tpa Copper Plant

As a case study, a comparison between the mine/mill and integrated plant economics is made in the table below, for a 100,000 tpa copper plant. As the table shows, the annual earnings for a 100,000 tpa copper plant are increased from US$31.2M to US$90.4M (an increase of US$59.2M) with an onsite refinery included in the project. This increase in earnings is realized through a capital expenditure of US$175M for the refinery.

Table 5 - Earnings Calculation for Mine/Mill Facility and Integrated Plant

Project			Mine / Mill	Integrated Plant
Gross Metal Sales	1.00$/lb Cu	US$ M/yr	$220.8	$227.9
Mine/Mill OPEX	0.47$/lb Cu	US$ M/yr	$103.3	$103.3
Downstream Costs	0.39$/lb Cu	US$ M/yr	$86.2	--
Refinery OPEX	0.12$/lb Cu	US$ M/yr	--	$34.2
Earnings (EBITDA)		US$ M/yr	$31.2	$90.4

The following table reports the pretax IRR and NPV of the 100,000 tpa copper plant. The IRR of the mine/mill project is quite low, at 3.2%. The addition of an onsite refinery improves the project economics to 11.3%, due to additional earnings of almost $60M per year. Interestingly, if one attributes this earnings increase to the refinery capital expenditure alone, the refinery capital generates a pretax IRR of almost 30%.

Project			Mine / Mill	Integrated Plant	Refinery
Mine/Mill CAPEX	5200 $/t Cu	US$ M	$520	$520	--
Refinery CAPEX	1750 $/t Cu	US$ M	--	$175	$175
Earnings (EBITDA)		US$ M/yr	$31.2	$90.4	$59.2
IRR (25Yr)			3.2%	11.3%	28.6%
NPV (25Yr, 10%)		US$ M	($220.0)	$65.0	$286.0

The following figure illustrates the difference in IRR between the mine/mill project vs. the mine/mill/refinery project, as well as indicating the IRR on the refinery CAPEX alone.

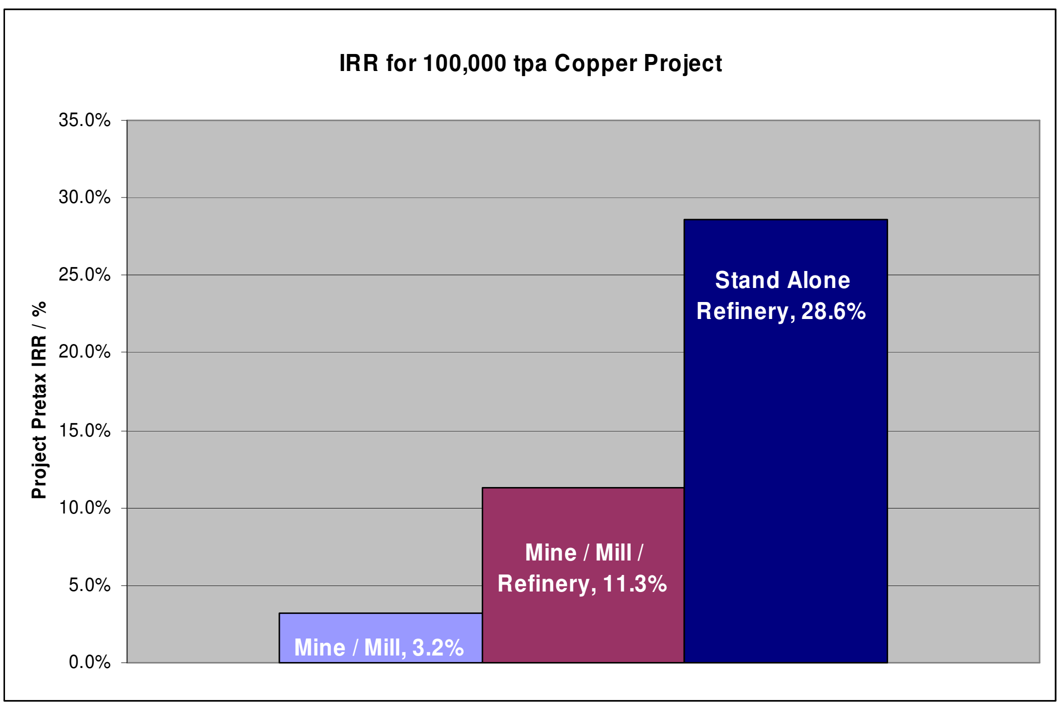

Figure 9 - IRR of Mine/Mill vs. Integrated Plant. 1.00$/lb Cu, TC/RC/PP/F of 39.1c/lb Cu.

Effect of Copper Price on Base Case

The following figure illustrates the impact of copper price upon the 100K copper project. This analysis assumes that TC/RC/PP remains constant with respect to copper price (23% of copper) and freight is steady at 95 $/t. As the figure illustrates, all project IRRs increase with increasing copper price.

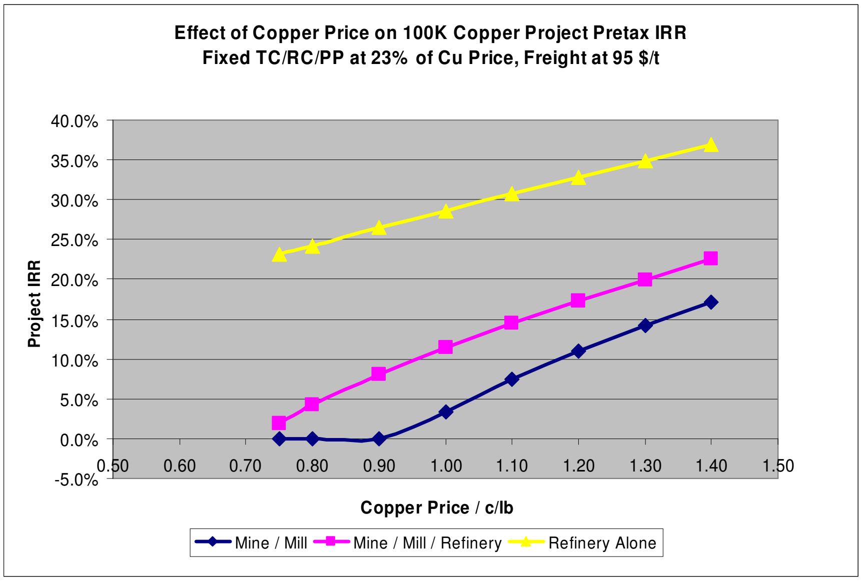

Figure 10 – The Effect of Copper Price on 100K Copper Plant IRR

As the above figure illustrates, IRR of all three projects increases at increasing copper prices. The integrated plant continues to show a better project IRR at all prices.

Effect of Total Downstream Costs on Base Case

The effect of the combined downstream costs on project IRR is reviewed in the figure below. For this analysis, the copper price was held at 1.00$/lb, and the combined TC/RC/PP/F was varied between 30 and 44 c/lb copper.

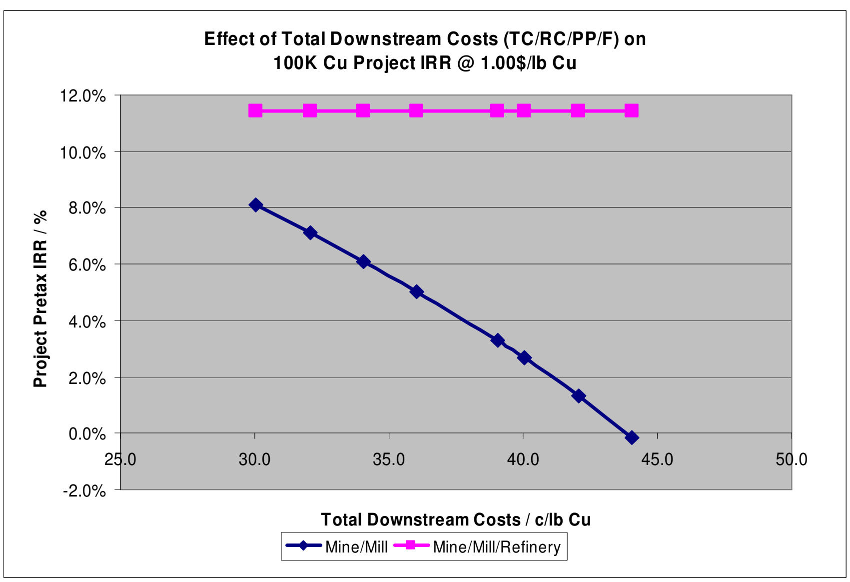

Figure 11 – The Effect of Downstream Costs (TC/RC/PP/F) on 100K Project IRR at Fixed Cu Price

As the preceding graph demonstrates, the IRR of the mine/mill project is significantly affected by downstream costs, but the integrated project is insulated from these variations. The following table illustrates the effect of downstream costs (at 30 and 44 c/lb copper) on mine/mill economics. The final line shows the IRR of the integrated plant, and demonstrates that project economic stability is achieved when an onsite refinery is utilized, as the IRR of the integrated project is 11.4%, and is independent of downstream costs.

Project		**30c/lb Cu**	**44c/lb Cu**
	TC/RC/PP/F	50/5/10%/95	105/10.5/10%/95
Gross Metal Value		$220.3 M/yr	$220.3 M/yr
Mine/Mill OPEX		$103.0 M/yr	$103.0 M/yr
Downstream Costs		$66.3 M/yr	$97.3 M/yr
EBITDA		$51.0 M/yr	$20.0 M/yr
IRR		8.1%	-0.2%
IRR of Integrated Plant		11.4%	11.4$

Effect of Concentrate Grade on Project IRR

One of the advantages of an onsite refinery is the ability to process a lower grade concentrate without the detriment of higher freight and treatment charges. The figure below demonstrates that the integrated project IRR is essentially independent of concentrate grade, within a reasonable window of 25% - 35% copper.

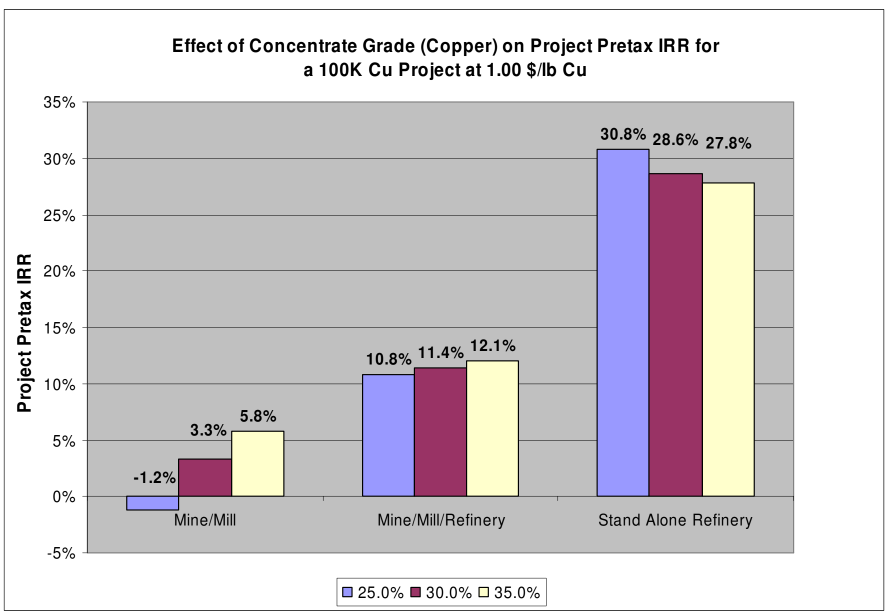

Figure 12 – The Effect of Concentrate Grade on 100K Project IRR

The one additional advantage of a lower grade concentrate, which is not shown in this analysis, is the reduction in mine/mill operating and capital costs, due to a higher mill recovery of copper to concentrate. Greater project value can obviously be realized when copper recovery from ore can be increased, even marginally.

Effect of Impurity Penalties

The following figure shows the pretax IRR for a mine / mill complex shipping concentrate to a smelter, while incurring $35/t impurity element penalties. As can be seen, an onsite CESL refinery allows for a much high IRR on capital, because the site is not subject to the downstream charges associated with arsenic bearing material. There are no additional operating costs associated with onsite refining of arsenic bearing materials, and thus the return of an integrated plant is independent of arsenic penalties.

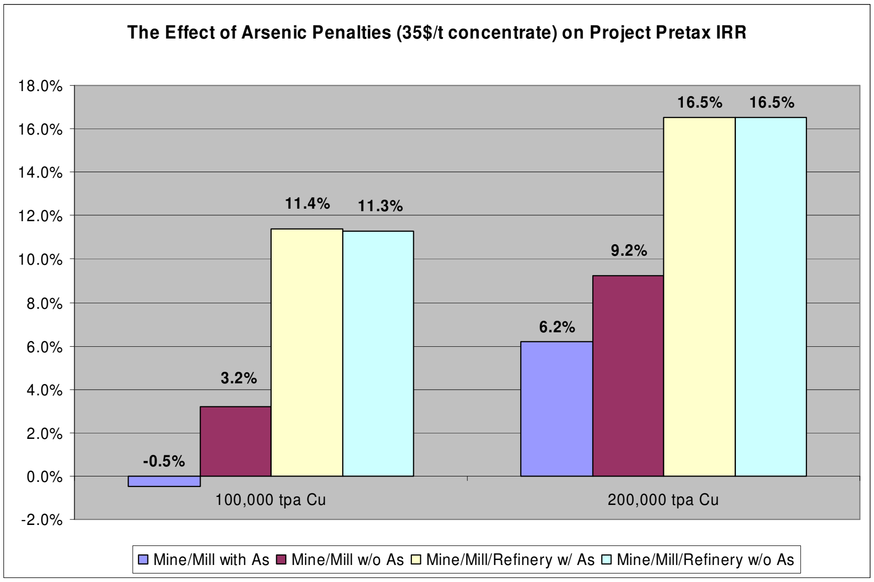

Figure 13 – The Effect of a $35/t Penalty Charge on 100K Project IRR

Effect of Sulphur Oxidation on Base Case IRR

The following figure illustrates the impact of sulphur oxidation on the stand alone refinery IRR. As can be seen, as sulphur oxidation increases, IRR of the project drops, due to increased operating and capital costs. Sulphur oxidation is one of the major cost drivers for the refinery, as it significantly impacts oxygen consumption, autoclave size, and limestone consumption.

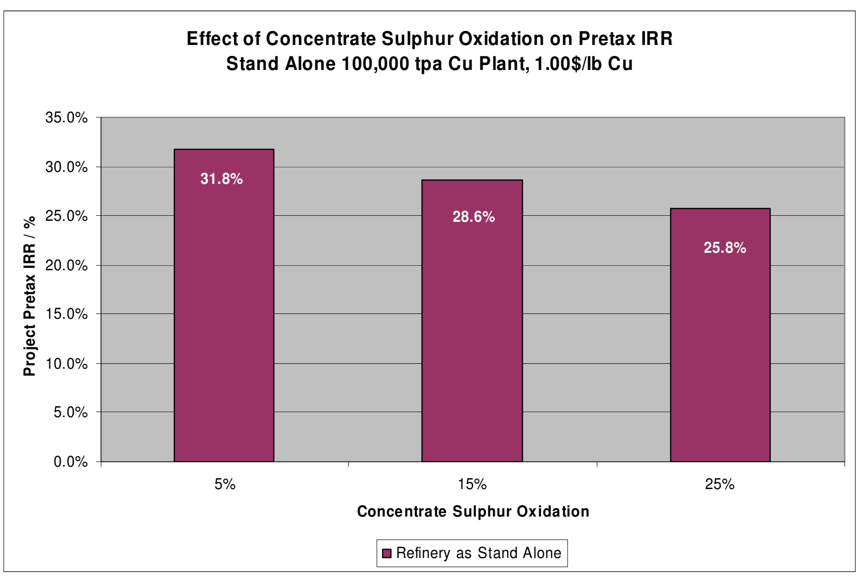

Figure 14 – The Impact of Refinery Sulphur Oxidation on 100K Project Refinery IRR

Effect of Power Cost on Base Case IRR

The figure below illustrates the effect of power on the stand alone refinery economics. As is shown, an increase in electricity cost from 3.5 to 5.0 c/kwhr results in a drop of 2.3% IRR. Power cost is a second major driver for refinery economics, as power consumption accounts for approximately 45% of the operating cost of the refinery, at 100,000tpa copper.

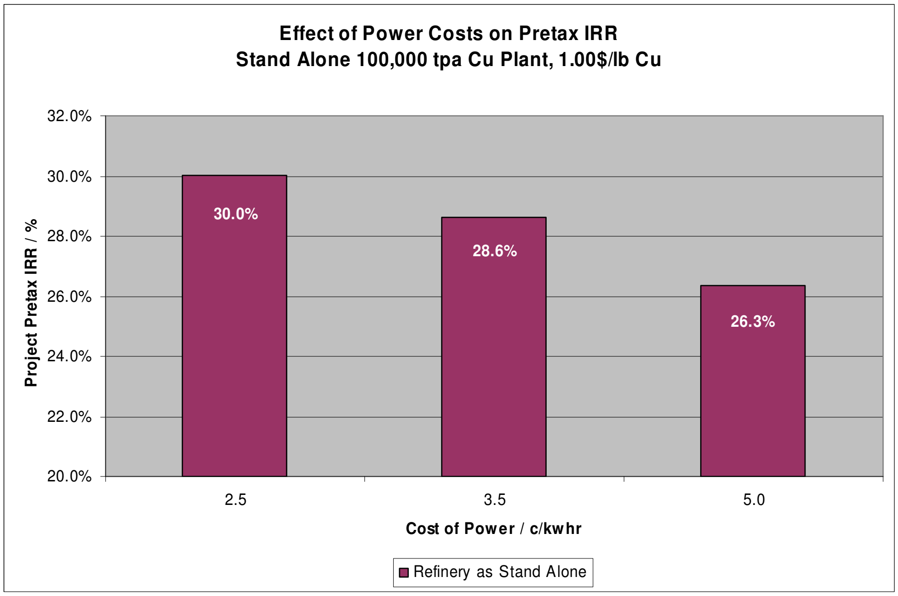

Figure 15 – The Effect of Power Costs on 100K Project Refinery IRR

Effect of Refinery Labour Rate on Project IRR

The following figure illustrates the effect of refinery labour rates on stand alone refinery IRR. As can be seen, the negative impact of high labour rates (60,000 US$/yr average vs. 30,000 US$/yr average) is exaggerated at the low end of the capacity range, due to the high contribution of labour to the operating cost. In general, only a small decrease in IRR, as labour is only a minor contribution to overall operating expenses.

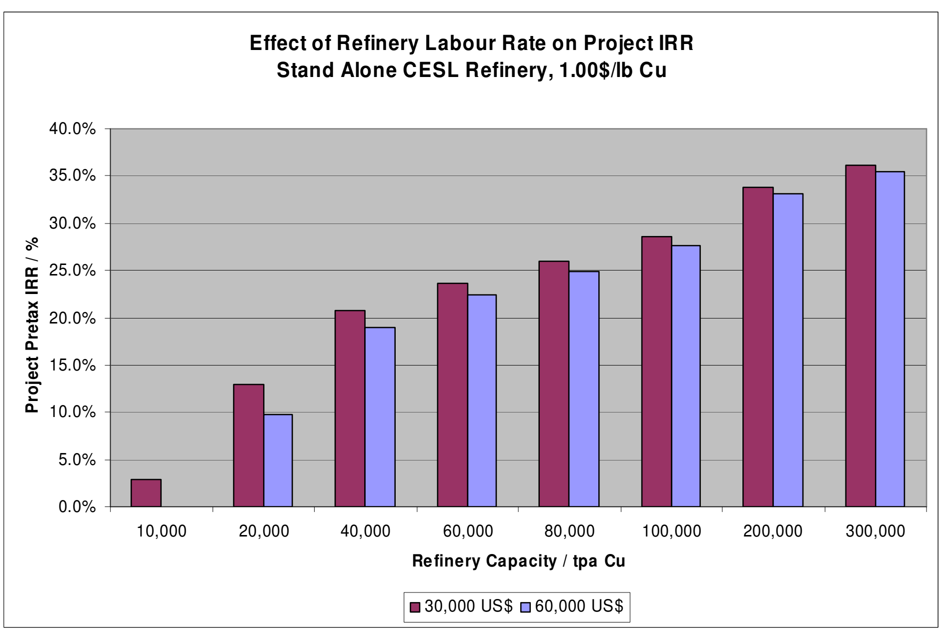

Figure 16 – The Effect of Refinery Operator Labour Rate on 100K Project Refinery IRR

4. CONCLUSION

The objective of this paper was to present a strong case for onsite refining of copper concentrate, over the traditional route of shipping to a smelter for processing. As has been presented in the preceding sections, there is a strong economic case to be made to process concentrate onsite.

5. CURRENT CESL DEVELOPMENTS

CESL has recently signed a memorandum of agreement with CVRD, regarding the building of a prototype CESL copper refinery in the Carájas region of Brazil. The project will have a capacity of 10,000 tpy copper cathodes. It is to be built and operated by CVRD with technical support from CESL, and is currently (Q2 2005), at the basic engineering phase. The detailed design is to be done by Hatch Engineering and SEI, with start up scheduled for Q2 2007. The purpose of the prototype refinery is to prove the CESL technology at this scale, for later use at the 235,000 tpy refinery treating concentrates from Salobo and Alemão. The project will also allow a transfer of knowledge from CESL to CVRD.

In addition to this major advancement in commercializing CESL's copper hydrometallurgy, CESL has also has made significant advances in modifying the CESL Process for precious metal recovery. This latter development, which is outside the scope of this paper, is significant in that the CESL copper technology can now be applied to copper-gold concentrates without (monetary) penalty with respect to the existing treatment by smelting/refining. Thus, the economic advantages discussed in this paper for copper concentrates apply equally well to those concentrate containing precious metals.

6. ACKNOWLEGEMENT

The authors would like to acknowledge that the inspiration for this paper was provided by John Marsden of Phelps Dodge, who presented an excellent paper on a related subject in October 2004 at the CIM Hydrometallurgy Conference on Pressure Hydrometallurgy, in Banff, Alberta, Canada.

Summary Table

Effects on IRR % (before tax)							
	Variable	Base Case	Variations	Mine/Mill Only	Integrated Mine/Mill/Refinery	Refinery Only	Comments
1	Capacity: TPY Cu	100k	10K to 300K			-9.4% for 40ktpy Cu +5.3% for 200ktpy Cu	
2	Cu Price ¢/lb Cu	100¢/lb	75¢/lb to 140¢/lb			+4% for +10¢/lb Cu	DSC Connected to Cu Price (23% of Price)
3	Downstream Costs ¢/lb Cu	39.1¢/lb	30¢/lb to 44¢/lb	-3% for 5¢/lb	No Effect	+5% for 5¢/lb DSC	Not Connected to Cu Price
4	Concentrate Grade % Cu	30%	25%, 35%			+20% for -5% grade -0.8% for +5% grade	
5	Power ¢/kWh	3.5¢	2.5¢, 5.0¢			+1.5% at 2.5¢/kWh -2% at 5¢/kWh	
6	Labour $/year operator	$30,000	$60,000			-1% at $60k for 100ktpy Cu -3.3% at $60k for 20ktpy Cu	
7	Sulphur Oxidation %	15%	5%, 25%			+3% for 5% S Ox -3% for 25% S Ox	
8	Impurity Penalty in Concentrate	0	$35/t	- 4%	0		