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LATIN AMERICAN MINING
OPPORTUNITIES AND DEVELOPMENTS

SUCCESSFUL DEVELOPMENT OF SOLVENT EXTRACTION IN LATIN AMERICA

by

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INTRODUCTION

Copper production by solvent extraction and electrowinning (SX-EW) undoubtedly came of age in the eighties. Now it appears to be the key that is unlocking the enormous copper potential of Latin America. Chile in particular is seeing a veritable "explosion" of new projects.

In this paper we are going to have a look at what is going on and why. But first, for the uninitiated, a few words about the SX/EW process itself.

WHAT IS COPPER SX-EW?

Basic Process

The SX/EW process is always preceded by some kind of leaching step. Thus leaching is included in the basic process depicted in Figure 1. As you can see, the combined process consists of three closed solution loops.

In Loop One, copper bearing solution (PLS) produced by leaching flows to the extraction section of the SX plant. Here it is contacted with a synthetic organic solution which selectively extracts the copper. The barren leach solution (raffinate) completes the loop back to leach more copper.

Loop Two, is within the SX plant proper. The loaded organic solution from extraction goes round to the stripping section. Highly acidic spent electrolyte solution from electrowinning strips the copper from the organic, which flows back around the loop to the extraction section.

Finally, in Loop Three, the strong electrolyte is sent to electrowinning. High purity cathode copper is deposited by electrolysis, and the spent electrolyte completes its loop back to the SX stripping section.

Simplistic Chemistry

The fundamental chemical reactions are outlined below. Although very simplistic, they tell us what we need to know to understand the main principles. To avoid complication, we have assumed simple sulfuric acid leaching of copper oxide:

Leaching	$CuO + H_2SO_4$	$\rightarrow CuSO_4 + H_2O$
SX Extraction	$CuSO_4 + Org.\ H_2$	$\rightarrow Org.\ Cu + H_2SO_4$
SX Stripping	$Org.\ Cu + H_2SO_4$	$\rightarrow Org.\ H_2 + CuSO_4$
Electrowinning	$CuSO_4 + H_2O$	$\rightarrow Cu + H_2SO_4 + \frac{1}{2}O_2$

The main points to note are:

The acid needed to leach copper is generated by the SX/EW process, and the net acid required for leaching is only that consumed by the gangue materials. In assessing reported acid consumptions, it is therefore important to know whether the figures refer to the gross consumption including the leaching of the copper, or the net amount after making allowance for the acid contribution from SX/EW. More than one has been caught unawares in the past.

The function of the organic is to selectively transfer copper into the EW circuit and thus achieve the purification and concentration required to produce high purity copper by EW. This is the key to the entire SX/EW process and is only possible because of the development of special synthetic organic liquids.

The EW step involves the electrolysis of water, which is the origin of the acid generated by SX/EW. Two implications of this are the emission of oxygen at the anodes which causes an acid misting problem, and the requirement for a continuous (though small) make-up of potable grade water. When using permanent stainless steel cathode plates, the current trend, this water must contain less than 30 ppm chloride, which must be taken into account when assessing the need for water treatment facilities.

Typical Modern Flowsheets

Typical flowsheets for SX and EW are shown in Figures 2 and 3. The SX process is carried out in mixer-settlers, usually comprising two or more mix boxes in series followed by a settling tank to separate the organic and aqueous phases. The case shown is typical for a heap leaching operation, with two stages in extraction and one stripping stage. There are many variations around the industry but this serves to illustrate the main features of the process.

Traces of the residual organic must be removed from the strong electrolyte prior to electrowinning. The flowsheet shows this carried out by flotation columns, which is a current trend. Many plants use filters for added safety.

Typically, there is a build up of solids/organic crud which must be removed for treatment by decantation, centrifuging or filtration to recover the valuable organic. Small quantities of organic extractant and diluent (high flash point kerosene) are lost from the circuit by entrainment in the raffinate. Diluent is also lost by evaporation. Many plants have covers over the mixer/settlers which reduces evaporation of diluent and keeps dust out.

Electrowinning is carried out in a number of cells through which the electrolyte is circulated. In the arrangement shown, the incoming strong electrolyte passes first through a small portion of the cells (scavengers) which act sacrificially as a last line of defense against contamination of the entire tankhouse with residual organic. Traditionally, the construction of the cells has been concrete with a flexible PVC liner. More recently, polymer concrete cells have been introduced, which are less likely to develop leaks. This is leading designers to locate the cells closer to ground level resulting in smaller buildings.

The cells contain lead based anodes and stainless steel cathode plates on which the copper is deposited. This arrangement is tending to replace the use of copper starting sheets, commonly seen in older plants. The stainless steel cathode plate approach is less labor intensive and allows closer spacing of the anodes and cathode plates. At about seven day intervals, cathode plates loaded with copper are transferred by crane to a washing and stripping facility. The degree of automation increases with the plant capacity.

A small amount of cobalt sulphate is added to the circulating electrolyte to minimize corrosion of the anodes. This lengthens the anode life and keeps the lead in the cathode product down to very low levels. (Some plants are adding guar as a cathode smoothing agent.)

The acid mist generated by electrowinning is suppressed by a thin layer of plastic beads floating on top of the cells.

For high efficiency and good product quality, the temperature of the electrowinning process should be maintained between 35° and 45° C. This is simply achieved by including a heat exchanger for the strong and spent electrolyte streams. About 5 - 10% of the EW power input generates heat, which is kept in the EW circuit by the heat exchanger (depending on climate, some plants also include a small steam or hot water heater for the strong electrolyte during winter).

There is normally a small net transfer of iron through SX, which accumulates in the EW circuit. This is frequently controlled by sending a small bleed of spent electrolyte to the extraction circuit. The copper content is recuperated by SX and the acid becomes part of the acid make-up to leach.

HOW DID IT GET STARTED?

Copper SX has its root in the 50's and 60's when SX was developed on a large scale for uranium extraction. Seeing the potential for copper, the General Mills Company (now Henkel) set out to develop an organic extractant for copper. This resulted in the introduction of LIX63 followed by LIX64 which was widely used in early plants. Other manufacturers such as ICI, Ashland, and Shell followed suit and developed similar extractants.

Key historical milestones are as follows:

- Development of LIX 63 and LIX 64 in early sixties by General Mills, USA.
- First small commercial plants at Ranchers Bluebird (1968) and Bagdad (1970), in Arizona
- First large scale plant at Chingola, Zambia, 1973 (100,000 TPA).
- First plant in Chile, Lo Aguirre, 1980 (16,000 TPA).
- Slow growth in seventies and early eighties.
- Continued improvements, better reagents, higher product purity.
- First EW plant to use ISA Process with stainless steel cathode plates, BHAS, Port Pirie, Australia, (4000 TPA).
- Rapid growth in eighties and early nineties.

HOW IS IT APPLIED?

Feed Solutions

Copper SX/EW has been successfully applied to two main types of solution, namely dilute sulfuric acid solutions and ammoniacal solutions. Copper contents can range from 0.5 to 35 g/l. The available organics are very tolerant to a wide range of impurities, especially for acid solutions.

The relatively few impurities which have to be watched can usually be catered for by proper design.

Commercial Applications

Commercial plants have been operated or are currently being built for the following broad range of applications:

- Dump leaching of oxide, sulfide or mixed ores
- Heap leaching of oxide, sulfide, or mixed ores with or without crushing
- Dump leaching of vat leach residues
- Vat leaching of oxide or mixed ores after crushing
- Agitated leaching of oxide or mixed ores after crushing and grinding
- Agitated leaching of flotation tailings
- Agitated leaching of roasted sulfide concentrates and oxide

concentrates

- In-situ leaching of oxide, sulfide, or mixed ores in old mine workings or shattered ore stopes
- Agitated leaching of smelter flue dust
- Mine waters
- Ammonia leaching of copper scrap
- Ammonia leaching of copper-lead dross
- Ammonia leaching of sulfide concentrates
- Acid-chloride leaching of copper-lead dross

Amenability of Ores to Acid Leaching

A good grasp of the potential leachability of copper minerals is essential for planning exploration programs with SX-EW in view.

Some broad guidelines for major mineral types are as follows:

Sulfuric Acid Leach Candidates

Azurite Malachite Tenorite Chrysocolla Brochantite Atacamite	Readily leachable at ambient temperature with dilute sulfuric acid. Kinetics suitable for dump, heap and agitated leaching.
Chalcocite	Partially leachable. Leachability can be increased by using strong acid cure.
Native Copper	Leachable when agitated with aerated, hot, strong acid.

Sulfuric Acid/Bioleach Candidates

Chalcocite Covellite Bornite	Leachable by acid/ferric iron solutions under bioleaching conditions, kinetics suitable for heap or dump leaching.
Cuprite Native Copper	Readily leached when mixed with above minerals in bioleaching system.
Chalcopyrite	Very slow leaching under bioleaching conditions. Kinetics suitable only for low grade dump leaching.

Important Points to Keep in Mind

Gangue mineralogy can have a decisive affect on suitability for leaching. High contents of acid consumers such as carbonates may render acid leaching uneconomic. In such cases alternative approaches such as ammonia leaching may be appropriate.

Gangue mineralogy may also have a major impact on the feasibility of heap leaching. For example, a high clay content may produce permeability problems.

In assessing sulfide ores, the precious metals content is all important, as they are not recovered by acid leaching. It may be possible to consider cyanidation after acid leaching, though the neutralization of the residual acid could be problematical, and the time delay may be unacceptable.

WHY IS IT SO POPULAR?

Advantages of SX/EW

Direct Production of High Grade Commodity

Probably the one biggest reason for it's popularity is that, coupled with leaching, it provides an opportunity to produce a premium grade commodity without further treatment by smelters and refineries. This is particularly attractive to small and medium size producers who do not have their own smelting and refining facilities.

Low Operating Cost

Despite the power requirement for EW, operating costs for SX-EW are relatively low. The ability of SX-EW operations to keep going during low copper price periods has been noted by many mining executives. The relatively low labor requirements especially when partnered by heap leaching are particularly attractive, and make operating in remote areas much more feasible.

Low Grade Ores

Together with heap or dump leaching, SX-EW can make it possible to economically process very low grade ores.

Small Operations Viable

Relatively small operations can be viable, depending of course on mining costs and infrastructure requirements.

Environmentally Clean

SX-EW is historically regarded as a "clean" process route. Air emissions and waste products are generally minimal.

The environmental aspects of the leaching step are also relatively favorable, though it varies depending on the particular process employed. The currently favored heap leaching process is generally regarded as having a low environmental impact, provided that the heap pads and ponds are equipped with impervious plastic or clay linings. However, reclamation plans, not required for older leaching operations, can involve considerable cost. This is especially true for sulfide ores which will tend to continue to bioleach over a long period of time.

Disadvantages

There is a significant power requirement for EW, which can increase the cost of local infrastructure.

The availability and cost of acid can have a major impact on economics. This is particularly true for oxide ores, while sulfide ores frequently generate their own acid.

For many situations, the numerous advantages, and relatively few disadvantages are making the SX/EW approach a very popular option.

WHY IS IT "TAKING OFF" IN LATIN AMERICA?

It is instructive to look at the factors behind the current explosive growth of copper SX/EW projects in Latin America, especially Chile.

Availability of Suitable Deposits

Perhaps the most obvious reason is the availability of suitable deposits. This is at least partially due to the coming of age of SX/EW technology, particularly in the USA where very large operations are routinely producing top quality copper. Thus, senior executives are now looking around through "SX/EW tinted glasses", whereas they once thought strictly in terms of regulation large sulfide deposits. The successful application of bacterial heap leaching to chalcocite ore has broadened the range of suitable deposits.

Positive Government Attitudes

Greater political stability and improved government attitudes towards private and foreign ownership have undoubtedly encouraged renewed mining industry interest in Latin America.

Favorable Environmental Climate

Opposition to mining from environmentalists is much less in Latin America than in the USA for example. Also, the time to obtain the necessary permits is shorter. Both of these factors shorten project development time and reduce costs in Latin America.

Availability of Acid

The availability of reasonably priced acid from existing copper smelters is a favorable factor near established copper mining centers.

Independence from Downstream Processing

Finally, as mentioned earlier, SX/EW presents the opportunity for small to medium size companies to produce a high purity commodity on the mine site, independent of downstream processing. This is a great incentive to both local and overseas companies, and makes it easier to obtain the necessary finance.

Growing Local Infrastructure

In Latin America, there is a growing local infrastructure of engineering, construction, and technical expertise, plus knowledgeable equipment suppliers and subcontractors. This is making it easier to develop smaller projects without the expense of extensive overseas support.

STATUS OF OPERATIONS IN LATIN AMERICA

Current SX-EW operations are located in Mexico, Peru and Chile as shown in Figure 4. Well known names include Cananea (Mexico); Cerro Verde (Peru); Lo Aguirre, El Soldado, El Teniente, Chuquicamata and Lince in Chile.

STATUS OF PROJECTS IN LATIN AMERICA

An indication of the quantity and location of SX-EW projects under development and future projects are shown on the maps in Figures 5 and 6.

A more detailed listing of some principal projects in Mexico, Peru and Chile is shown in Table 1 with capacities and potential implementation dates.

These lists say an additional one and a half million to two million tons of electrowon cathode will come on stream in Latin America before the year 2000.

TECHNICAL TRENDS IN LATIN AMERICA

While Mexico, Peru and other Latin American countries will be active in SX-EW development, the focus of most of the recent activity has been in Chile. New projects there, some of them very large, tend to reflect current international SX-EW plant design trends due to the involvement of overseas mining companies and engineering firms. However, there are also technical features which reflect particular ore types and other specific conditions such as water quality. Also there are innovations and design trends evolving from the growing body of local technical and engineering expertise. Some of the technical trends are described briefly below.

SMP Acid Cure Process

Following the lead of SMP, a Chilean Company, a number of projects have adopted acid cure and shallow heap leaching which has five main advantages:

- Agglomerating effect allows a fine crush size.
- Agglomeration allows high solution application rates.
- Acid cure accelerates leach kinetics and shortens cycle time.
- The concentrated acid helps to solubilize a portion of the sulfide ore content.
- The solution pH is lowered very rapidly to a level favorable for the establishment of bioleaching for sulfides.

As with most technologies, this approach is best suited to particular ore types.

Use of High Chloride Water for Leaching

Because of the absence of fresh water, some projects have had to consider the use of highly saline water, even sea water, for leaching. The Lince project in north Chile, for example, has successfully married sea water leaching with SX/EW. In such cases, an additional mixer-settler is required to wash chloride from the loaded organic. Only low levels of chloride can be tolerated in EW, especially with permanent stainless steel cathode plates.

Countercurrent Leaching

New heap leaching system designs tend to include provision for intermediate recirculation to facilitate the maintenance of the target solution grade in the SX feed while maximizing recovery. Raffinate from SX is recirculated over partially depleted heaps, then applied to fresher heaps thus achieving a countercurrent flow pattern. This type of system also allows for more effective control of acid levels.

Electrolyte Clean-up

Various innovations are being tried for the clean up of electrolyte prior to electrowinning. This is of particular importance to Chilean projects such as Chuquicamata which contain manganese in the leach solution. New methods include flotation columns, coalescers, and alternative filters.

Crud Treatment

Chuquicamata have developed an effective method of crud treatment. Crud is mixed with organic then decanted. Most of the valuable organic in the crud is recuperated into the organic medium.

HPDE Lined Settlers

Plants in Chile and Mexico have adopted HPDE lined concrete for SX settler construction. This is a relatively inexpensive material and is suitable for high chloride solutions.

Polymer Concrete EW Cells

Traditional PVC lined concrete EW cells are being replaced by polymer concrete units in many new plants. As stated earlier, these make it feasible to consider locating the cells at ground level.

Stainless Steel Cathode Plate

Permanent stainless steel cathode plates are increasingly replacing copper starting sheets. Local manufacturers are now competing in this field.

Leaching

Overall there appears to be a definite trend towards the treatment of sulfide ores. The most common approach is bacterial assisted heap leaching, though one major project is looking at ammonia leaching of sulfide concentrates, which was practiced commercially by Anaconda in Montana in the seventies.

WHAT DOES THE FUTURE HOLD?

It is always difficult to make authoritative predictions about overall trends in the copper industry, or indeed in the mining industry as a whole. Having said that, there are a number of important factors which will help to shape the future of Latin American copper industry in general and the SX-EW sector in particular.

Copper Production

The projections of new copper production do point to Latin America's dominant position in the World's production of copper and the leading role of SX-EW in the expansion of production.

Political Climate

Favorable government attitudes have undoubtedly been a major factor in encouraging the extraordinary proliferation of projects we are now seeing especially in Chile. Mexico is also now perceived to be favorable for exploration and project development. Many see Peru having great potential as terrorism is brought under control.

In common with worldwide trends, privatization appears to be in favor, in stark contrast to the events of the sixties and seventies. Even Cuba, having lost Soviet support, is beginning to open up to foreign investment. Obviously whether or not this trend continues will have a major and probably decisive effect on future growth. SX-EW technology in particular provides opportunity for small projects. Given a favorable political climate, we could see projects springing up in Latin American countries which heretofore have not had a significant copper mining industry.

Environmental Issues

Although Latin American countries are aware of the importance of responsible environmental protection, as indeed is the mining industry as a whole, it is fair to say that anti mining attitudes and over regulation have not become as entrenched as in some other nations. Future trends in this area are obviously crucial to the continued growth and spread of copper projects.

Generally speaking, SX-EW is currently perceived by the public as environmentally friendly technology, compared with say copper smelting. Thus if the environmental climate should worsen, it should fare better.

NAFTA

Copper mining is, of course, in an entirely different category to manufacturing or even down-stream processing of copper intermediates. The mines and therefore the SX-EW plants are where they are and cannot be moved to take advantage of cheaper labor or any other favorable factors.

In the first instance, Mexico may receive impetus in mining because of the easier access for U.S. and Canadian mining companies, and the ready access to the USA and Canada for Mexican producers.

A potentially negative factor could be the spread of less favorable environmental regulations and permitting processes, if pressure mounts for uniform environmental regulations throughout the NAFTA region.

Looking further ahead, the big question is whether other Latin American countries would become members of NAFTA, following the pattern of the E.C. There could be significant ramifications for the copper industry if, for example, Chile joins NAFTA.

Technical Innovations

The coming of age of SX/EW technology is already having a major effect in expanding copper production in Latin America. Judging from the growing list of projects we can expect continued expansion.

In the past, the flow of innovations has tended to be into the region from the outside. However, as the numbers of new SX/EW operations in Latin America grows, the flow will be reversed, to some degree. In fact this has already started to happen, and Latin American SX/EW operations are on the beaten path for outsiders who wish to view the latest technical developments and plant design trends.

In general, future innovations will tend to improve the economics of SX/EW and make it even more attractive. Developments in leaching, especially for sulfide ores, may well turn presently undeveloped ore deposits into viable projects.

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Figure 1
BASIC PROCESS

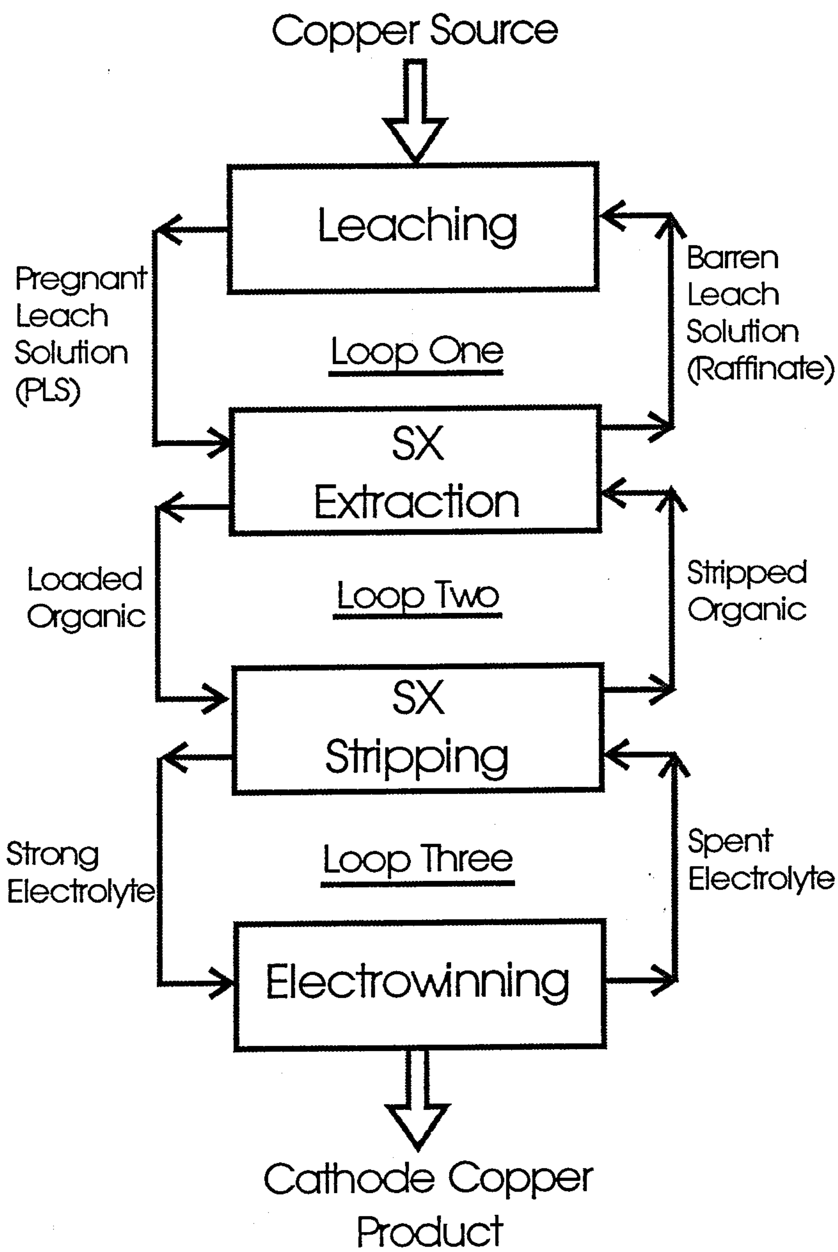

Figure 2
TYPICAL SX FLOWSHEET

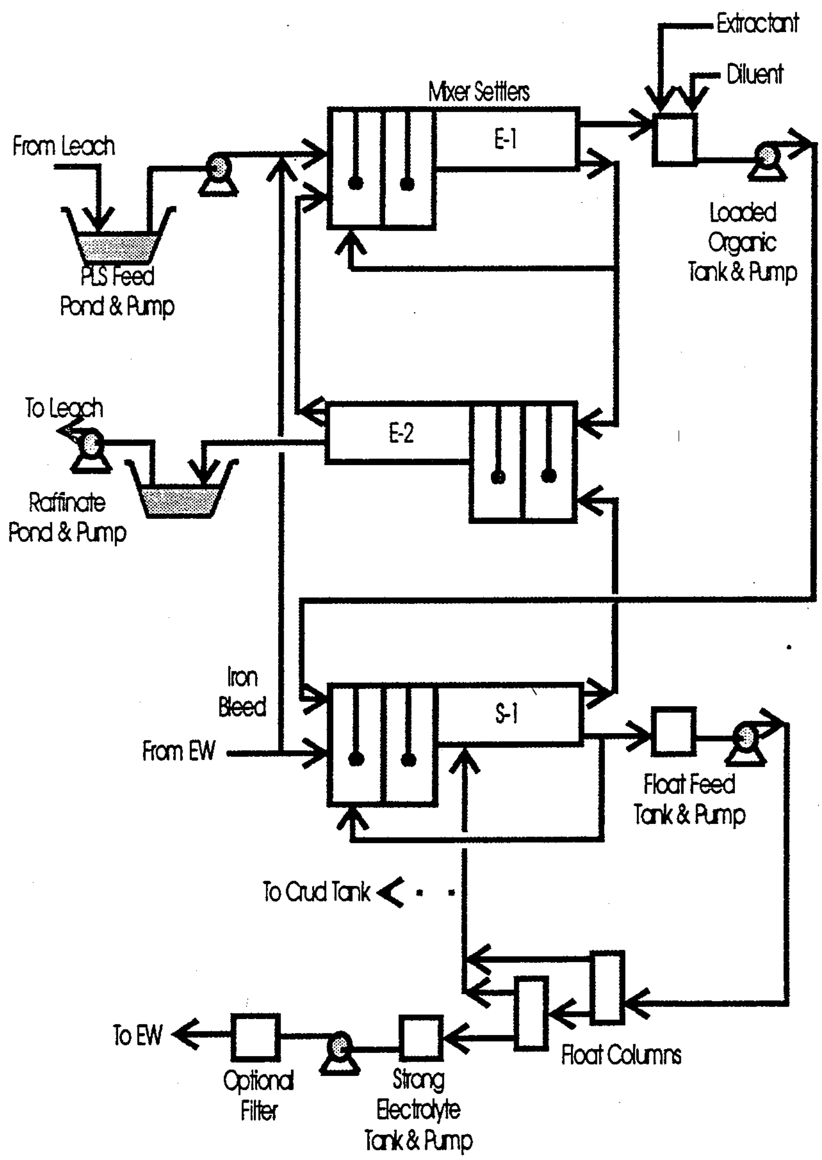

Figure 3
TYPICAL EW FLOWSHEET

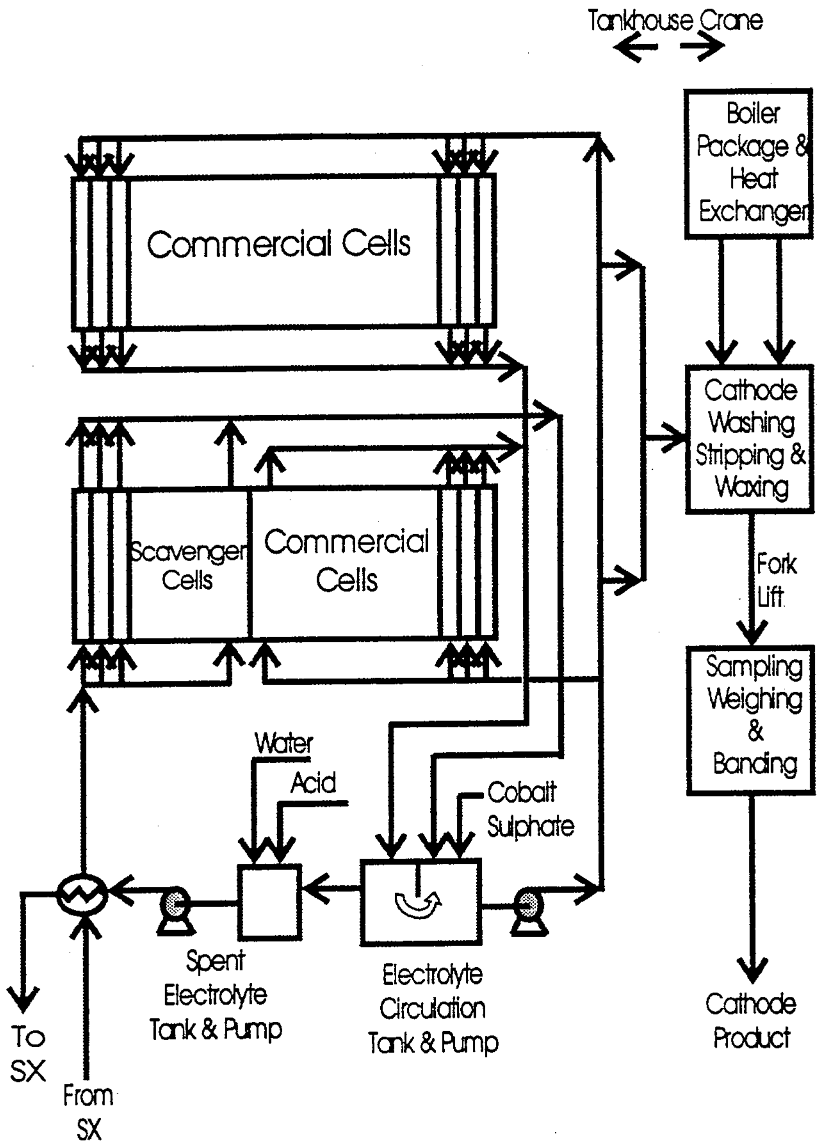

Figure 4
LATIN AMERICAN COPPER SX-EW PRODUCERS CURRENT

Figure 5
LATIN AMERICAN COPPER SX-EW PRODUCERS UNDER DEVELOPMENT

Figure 6
LATIN AMERICAN COPPER SX-EW PRODUCERS FUTURE PROJECTS

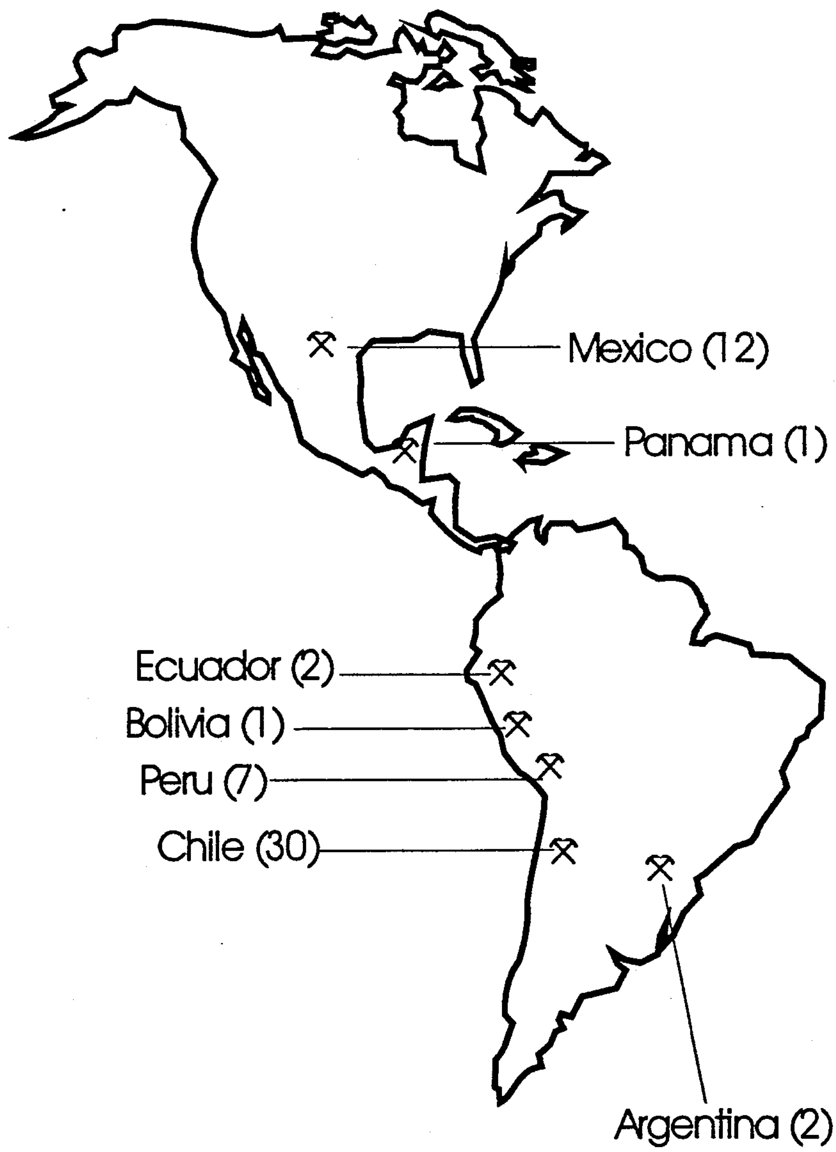

TABLE 1
SX-EW PROJECTS
LATIN AMERICA

MEXICO			
Mexicana De Cobre	- La Caridad	30,000 tpy	1996
PERU			
Southern Peru Copper	- Toquepala	50,000 tpy	1996
Minero Peru	- Cerro Verde Expansion	30,000 tpy	1997
Mantos Blancos	- Quellaveco	100,000 tpy	1997
CHILE			
Codelco			
Div. El Salvador	- Oxidos Quebrada M	12,500 tpa	1994
	- Quebrada M, Etapa II	12,500 tpa	1995
	- Quebrada M, Etapa III	15,000 tpa	1996
Codelco			
Div. Chuquicamata	- Sulfuros de Baja Ley	12,500 tpa	1994
	- Ripios, Etapa II	40,000 tpa	1996
	- Relaves Talabre	36,000 tpa	1999
Codelco			
Div. El Teniente	- Quebrada Teniente	10,000 tpa	1996
Codelco			
Div. R. Tomic	- Radomiro Tomic	150,000 tpa	1995
Codelco/Cyprus/Lac Minerals			
Joint Venture	- El Abra	120,000 tpa	1996
Quebrada Blanca	- Q.B. Proyecto en Curso	75,000 tpa	1994
Cerro Colorado	- C.C. Proyecto en Curso	45,000 tpa	1993
	- C.C. Expansion	15,000 tpa	1995
BHP Escondida	- LX Concentrados	80,000 tpa	1996
	- LX Oxidados	80,000 tpa	1998
Outokumpu/Placer	- Zaldivar	120,000 tpa	1996
Equatorial	- Leonor	30,000 tpa	1995
Michilla	- 1a. Ampliación Lince	5,000 tpa	1993
	- Expansión Lince	30,000 tpa	1995
Punta Del Cobre	- S.P.C. Proyecto en Curso	7,000 tpa	1993
Mantos Blancos	- Manto Verde	42,500 tpa	1995
	- Santa Bárbara	33,000 tpa	1995
	- Expansión Baja Ley	33,000 tpa	1997
	- Ripios Antiguos Lixiv.	33,000 tpa	1999

TABLE 1 - Continued
SX-EW PROJECTS
LATIN AMERICA

CHILE

Minera Rayrock	- Iván/Zar	12,000 tpa	1996
Eulogio Gordo	- Caleta El Cobre	12,000 tpa	1995
C.M. Doña Ines	- Collahuasi	225,000 tpa	1997
Cyprus Copper	- Chimborazo	50,000 tpa	1998
Minera San Martin	- Tuina	10,000 tpa	1994
Sahli Hochschild	- Venado Sur	10,000 tpa	1996
Minera Doña Ada	- Sierra Gorda	10,000 tpa	1996
Enami	- Reconversi6n Plantas	10,000 tpa	1996