The Intec Copper Process
Table of Contents

1 Introduction .................................................................................................................................... 3

2 Intec Process Background ............................................................................................................. 4
   2.1 Halide Lixiviants .......................................................................................................................... 4
   2.2 Leaching Processes ...................................................................................................................... 5
      2.2.1 Sulphides ................................................................................................................................ 5
      2.2.2 Oxides .................................................................................................................................... 6
      2.2.3 Arsenic Bearing Feedstocks .................................................................................................... 6
      2.2.4 Iron Residue .......................................................................................................................... 6
      2.2.5 Leach Conditions Summary .................................................................................................. 7
      2.2.6 Leach Circuit Design ............................................................................................................. 7
      2.2.7 Co-Current Leaching (Cupric System) .................................................................................. 8
      2.2.8 Counter-Current Leaching (Cuprous System) ....................................................................... 8
   2.3 Copper Recovery Options .......................................................................................................... 9
      2.3.1 Copper Halide Electrowinning ............................................................................................. 9
      2.3.2 Solvent Extraction of Copper from Halide Solutions ............................................................ 10
      2.3.3 Copper Oxychloride Precipitation .......................................................................................... 11
   2.4 By-Product Credit Metals Recovery Options ............................................................................. 11
      2.4.1 Gold ....................................................................................................................................... 12
      2.4.2 Silver ..................................................................................................................................... 12
      2.4.3 Indium .................................................................................................................................... 12
      2.4.4 Bismuth .................................................................................................................................. 12

3 Intec Process Advantages .............................................................................................................. 13
   3.1 Intec Process vs. Smelters .......................................................................................................... 13
   3.2 Intec Process vs. Sulphate Hydrometallurgy ............................................................................. 13

4 Intec Process Economics .............................................................................................................. 15
   4.1 Intec Process Economics vs. Competing Technologies ............................................................. 15
   4.2 Intec Process Economic Models ................................................................................................ 16

5 Intec Process Environmental Advantages ..................................................................................... 18
   5.1 Life Cycle Analysis ..................................................................................................................... 18
1 Introduction

The Intec Process is a family of patented hydrometallurgical technologies for the recovery of base and precious metals from sulphide and oxide feedstocks. It is based on the use of halide (chloride, bromide and iodide) chemistry to solubilise metals through the leaching process, followed by the recovery of high purity metals by electrowinning or chemical salts.

This document summarises the application of the technology for recovery of copper and associated co-product or by-product metals, and is divided into three main sections with a particular emphasis on its comparison with existing copper recovery technologies. Firstly, the technical aspects of the process are explained, especially the ability of the Intec Process to accommodate large variations in feedstock with respect to feedstock mineralogy, metal content and project size. The second section provides an economic summary at varying production rates including comparison with the economics of competing technologies. Finally, the environmental benefits of the Intec Process are also described.
2 Intec Process Background

The patented Intec Copper Process was developed for the recovery of copper metal at LME Grade A purity. Essentially, the process consists of leaching, purification and product recovery (electrowinning or other); however the unit operations can be adjusted based on the feedstock composition, quantity and location in order to optimise economic returns.

An example flowsheet of the process is shown in Figure 2-1. Fewer or additional unit operations may be required depending on feedstock characteristics.

2.1 Halide Lixiviants

The solubility of metals is significantly enhanced in the presence of concentrated halide brines. For example gold, silver and lead are readily solubilised in the Intec Process liquors, while they remain virtually insoluble in the sulphate lixiviants of competing hydrometallurgical technologies. Furthermore, a broader range of metallic species are also stable in halide liquors, such as the cuprous oxidation state of copper (Cu⁺), which does not exist in sulphate.

The Intec Process brine matrix typically uses a total halide concentration of 6-8 moles/litre, with a boiling point of 115-120 °C. The chloride components are a mixture of sodium and calcium chloride; with the ratio depending on overall halide requirements for metal solubility, and the calcium required for sulphate precipitation.

The mixed halide system – usually using sodium bromide in conjunction with sodium/calcium chloride - is at the core of Intec’s patents for metal recovery by halide electrowinning. The Intec Process anode forms the powerful oxidant called Halex™ (NaBrCl₂), which is soluble in the process liquor and is readily recycled through the closed loop system, providing the primary driving force to the leach step.
Bromide and iodide also enhance the stability of precious metals such as gold and silver. In some applications of the Intec Copper Process, trace amounts of sodium iodide are selectively added to enhance gold recovery.

The high metal leaching rates and efficiencies associated with the Intec Process leach create some challenges for the physical plant. As such, the appropriate selection of materials of construction is important to ensure longevity of equipment. All wetted parts of the plant are fabricated from high performance plastics, or in some sections exotic alloys or titanium.

Reactors are typically constructed from comparatively inexpensive fibreglass reinforced plastic (FRP) using Derakane 470-300 resin, which permits continuous operation at 130 °C. The costs are similar to or less than equivalent steel tanks. Various linings can be used where required for additional protection, e.g., in high wear zones. Titanium or coated steel agitators have been successfully used, with the final design specific for the mixing duties required. Piping is generally a mixture of PVDF, FRP or random co-polymer polypropylene depending on temperature and pressure duties.

The performance of these items of equipment has been systematically and successfully proven by Intec at both laboratory and demonstration plant scales, along with ancillary items such as instrumentation, heat-exchangers, ducting, structural framework, and control systems.

### 2.2 Leaching Processes

There are two types of feedstock; metal-sulphides (e.g., the common copper sulphide minerals CuFeS$_2$, CuS, and Cu$_2$S) and metal-oxides (e.g., CuO and Cu$_2$O).

The Intec technology has been applied to a wide range of copper-bearing minerals, and a summary of the typical leach conditions is given in Table 2-1. Notwithstanding the feedstock-specific limitations of particle size and mineral occlusion, typically 98% (95-99.5%) extraction of copper is achieved, and co-extraction of credit metals (e.g., gold, silver, indium, bismuth, etc.) is similarly high.

#### 2.2.1 Sulphides

Metal sulphides are oxidised by sparging air to supply oxygen and the recycling of liquid anolyte from the halide electrowinning cell (occasionally, with top up reagent acid), as shown in Reactions 1 and 2.

\[
4\text{CuFeS}_2(s) + 5\text{O}_2 + 20\text{HCl} \rightarrow 4\text{CuCl}_2 + 4\text{FeCl}_3 + 8\text{S}(s) + 10\text{H}_2\text{O} \quad \text{RXN 1}
\]

\[
2\text{CuFeS}_2(s) + 5\text{NaBrCl}_2 \rightarrow 2\text{CuCl}_2 + 2\text{FeCl}_3 + 4\text{S}(s) + 5\text{NaBr} \quad \text{RXN 2}
\]

An oxidation-reduction couple (e.g., Cu$^+ \leftrightarrow$ Cu$^{2+} + e^-$) is employed to facilitate the transfer of oxygen as shown in Reactions 3 and 4. Put simply, the copper acts as a ‘catalyst’ to maximise the efficiency of oxygen uptake by the process liquor.

\[
4\text{CuCl} + \text{O}_2(s) + 4\text{HCl} \rightarrow 4\text{CuCl}_2 + 2\text{H}_2\text{O} \quad \text{RXN 3}
\]

\[
\text{CuFeS}_2(s) + 4\text{CuCl}_2 \rightarrow 5\text{CuCl} + \text{FeCl}_3 + 2\text{S}(s) \quad \text{RXN 4}
\]

As may be seen in Reactions 1 and 2, the sulphide component (S$^2$) is only partially oxidised to elemental sulphur (S), resulting in a significant reduction in the total oxygen requirement for the
system. By comparison, sulphate-based pressure oxidation technologies commonly oxidise sulphur to sulphate ($SO_4^{2-}$).

### 2.2.2 Oxides

Metal oxides are leached with acid, which is normally added to the circuit according to Reaction 5. In the case where mixed oxide and sulphide minerals are processed, acid can be generated in-situ via the oxidation of sulphur or sulphides (e.g. the oxidation of pyrite as shown in Reaction 6) and this can be a cheaper alternative to purchasing fresh acid in certain situations.

\[
CuO(s) + 2HCl \rightarrow CuCl_2 + H_2O \quad \text{RXN 5}
\]

\[
2FeS_2(s) + 15NaBrCl_2 + 4CaCl_2 + 16H_2O \rightarrow 2FeCl_3 + 4CaSO_4(s) + 32HCl + 15NaBr \quad \text{RXN 6}
\]

Where acid is added directly to the process, sulphuric acid is purchased, as it is a lower cost reagent than hydrochloric acid. The calcium chloride in the process liquor reacts with the sulphate to form calcium sulphate and hydrochloric acid according to Reaction 7. Due to the high temperatures in the circuit and the concentrated halide brine used in the Intec Process, the anhydrous form of calcium sulphate (anhydrite) is precipitated, as opposed to the hydrated form (gypsum). The anhydrite is highly crystalline and does not form scale on the process equipment, as is normally the case with gypsum in sulphate-based systems.

\[
H_2SO_4 + CaCl_2 \rightarrow 2HCl + CaSO_4(s) \quad \text{RXN 7}
\]

### 2.2.3 Arsenic Bearing Feedstocks

One of the major environmental reasons for selecting hydrometallurgical processing rather than smelting for many copper concentrates is the presence of arsenic. Arsenic is a toxic metal which is difficult to control in the off-gas from smelter operations. As such, an upper limit of 0.5% arsenic in the concentrate feedstocks is normally applied by smelters.

In the Intec Process leach circuit, arsenic is readily leached and re-precipitated as highly crystalline ferric arsenate according to Reactions 8 and 9. The crystalline ferric arsenate readily passes conventional TCLP and MEP tests as a measure of environmental stability. In recognition of this, a NSW EPA approval was granted to Intec in 1999/2000 for disposal of leach residue containing ferric arsenate into conventional landfill. Feedstocks containing up to 10% arsenic have been successfully treated by this method.

\[
FeAsS + 7CuCl_2 + 4H_2O \rightarrow FeCl_3 + 7CuCl + S + H_3AsO_4 + 5HCl \quad \text{RXN 8}
\]

\[
H_3AsO_4 + FeCl_3 \rightarrow FeAsO_4(s) + H_2O \quad \text{RXN9}
\]

### 2.2.4 Iron Residue

A potential issue for any process leach circuit is control and precipitation of solubilised iron. Many technologies encounter significant difficulty with the physical handling, filtration and poor environmental stability of precipitated iron wastes.

Leaching of copper minerals using the Intec Process is conducted in the pH range of 1-2, where leachable iron is re-precipitated as hematite according to Reaction 10. The acid generated in this reaction is re-used to oxidise the copper cations as shown in Reaction 11.

\[
Fe_2O_3(s) + 3H_2SO_4 \rightarrow 4SO_2 + 3H_2O + 2FeCl_3 \quad \text{RXN 10}
\]
\[ 2\text{FeCl}_3 + 3\text{H}_2\text{O} \rightarrow \text{Fe}_2\text{O}_3(s) + 6\text{HCl} \]  
RXN 10

\[ 4\text{CuCl} + 4\text{HCl} + \text{O}_2 \rightarrow 4\text{CuCl}_2 + 2\text{H}_2\text{O} \]  
RXN 11

The hematite is crystalline and is thus readily filterable. Hematite is one of the most stable forms of iron, and extensive testing has demonstrated that hematite product is environmentally stable, unlike iron jarosites.

### 2.2.5 Leach Conditions Summary

The Intec Process technology has been applied to a wide range of copper-bearing minerals at the laboratory, pilot and/or demonstration plant scales. Table 2-1 summarises the required leach conditions for copper-bearing minerals suitable for processing by the Intec Process.

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Formula</th>
<th>Conditions</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sulfides</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chalcoctite</td>
<td>Cu$_2$S</td>
<td>75-85 °C</td>
<td>Rapid leaching behaviour</td>
</tr>
<tr>
<td>Covellite</td>
<td>CuS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chalcopryte</td>
<td>CuFeS$_2$</td>
<td>85 °C</td>
<td>Moderate leaching behaviour</td>
</tr>
<tr>
<td>Bornite</td>
<td>Cu$_3$FeS$_4$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enargite</td>
<td>Cu$_3$AsS$_4$</td>
<td>95-100°C</td>
<td>Slow leach kinetics which can be enhanced by additives</td>
</tr>
<tr>
<td>Tennantite</td>
<td>Cu$_6$As$_2$S$_7$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tetrahedrite</td>
<td>4Cu$_3$S$_3$Sb$_2$S$_4$</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Oxides</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Azurite</td>
<td>2CuCO$_3$.Cu(OH)$_2$</td>
<td>&gt;30 °C</td>
<td>Rapid leaching behaviour</td>
</tr>
<tr>
<td>Cuprite</td>
<td>Cu$_2$O</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Malachite</td>
<td>CuCO$_3$.Cu(OH)$_2$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tenorite</td>
<td>CuO</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Native</td>
<td>Cu</td>
<td>75-85 °C</td>
<td>Rapid leaching behaviour</td>
</tr>
</tbody>
</table>

### 2.2.6 Leach Circuit Design

Two example leach circuit designs have been provided to showing the use of soluble copper in the cupric (Cu$^{2+}$) or cuprous (Cu$^+$) state. A cupric-based system would be appropriate to smaller projects producing intermediate copper products or mixed-technology projects, while a cuprous-based system would be appropriate for the production of high-purity copper metal via electrowinning.

The simpler cupric system uses a single train of leach tanks, whereas the cuprous system uses a three-stage counter-current circuit. A diagram of each circuit is shown in Figure 2-2.
2.2.7 Co-Current Leaching (Cupric System)

Cupric ions are ideal for the direct precipitation of copper oxychloride, or solvent extraction circuits which can be linked to sulphate electrowinning or salt crystallisation units.

The leach conditions in the single train are highly oxidative in every tank, which affords the most economical leach circuit. However, these savings must be weighed against the additional costs of copper recovery from the cupric state if electrowinning is used as the final recovery step. This would typically only be the case where copper was present as a by-product to a higher-value metal in the feedstock, such as gold.

2.2.8 Counter-Current Leaching (Cuprous System)

Cuprous ions are ideal for direct halide electrowinning, with about half the energy cost of electrowinning from the cupric state (used in all other sulphate-based copper electrowinning technologies). As such, counter-current leaching is appropriate for larger projects with dedicated Intec Process electrowinning plants for production of high-grade copper metal.

The leach conditions in the counter-current circuit vary from tank to tank, to ensure that copper exiting the leach is in the cuprous oxidation state. Additional cost is required for the thickeners, and this also adds complexity for process control. However, at large production scales these costs are offset by significant energy savings from the electrowinning of cuprous copper.
2.3 Copper Recovery Options

2.3.1 Copper Halide Electrowinning

Intec has developed a copper electrowinning cell specifically for cuprous (CuCl) and cupric (CuCl₂) systems. The cell is divided into two compartments via a porous diaphragm (conventional filter cloth). The feed solution is directed to the cathode compartment, where metallic copper dendrites are electrowon onto a patented corrugated titanium cathode (Reaction 12). The depleted solution passes through the diaphragm into the anode chamber, where NaBrCl₂ is generated at the anode (Reaction 13). Some pictures of the titanium cathode (wiped and un-wiped), copper dendrite, as well as the conveyor are given in Figure 2-3.

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cathode</td>
<td>CuCl → Cu⁺ + Cl⁻ + 2e⁻</td>
</tr>
<tr>
<td>Anode</td>
<td>NaBr + 2Cl⁻ + 2e⁻ → NaBrCl₂</td>
</tr>
<tr>
<td>Overall</td>
<td>2CuCl + NaBr → Cu(s) + NaBrCl₂</td>
</tr>
</tbody>
</table>

Figure 2-3: (TOP LEFT) Titanium corrugated cathode, (TOP RIGHT) Dendrite, (BOTTOM LEFT) Un-wiped titanium cathode, (BOTTOM RIGHT) Copper dendrites being removed from the EW cell by conveyor belt

The sodium bromo-chlorine complex called Halex™ is a dissolved species with a low vapour pressure. Halex behaves like chlorine gas in terms of oxidation power and chemistry, but with obvious considerable handling advantages compared to a gas. It has a potential of around +1000 mV (vs Ag/AgCl) and is highly reactive. As a liquid, the oxidant is easily recycled to the leach circuit, where it is more easily utilised than a gas. Halex enhances the leaching of refractory minerals, which often host gold.
Importantly, the Halex species is unique to the Intec Process, being derived from the use of mixed-halide lixiviants. This intellectual property is secured by over two hundred international patents in seven patent families that are constantly being updated as part of an ‘evergreening’ strategy.

Intec has operated a number of cells ranging from laboratory scale to the full commercial 1 tonne per day scale. Larger plants would use multiples of the 1 tonne per day cell. The nominal operating conditions are summarised in Table 2-2.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current Density</td>
<td>500-1000 A/m²</td>
<td>Average in sulphate EW is 400 A/m²</td>
</tr>
<tr>
<td>Cell voltage</td>
<td>2.4-3.2 V</td>
<td></td>
</tr>
<tr>
<td>Cell efficiency</td>
<td>&gt;98 %</td>
<td></td>
</tr>
<tr>
<td>Metal Purity</td>
<td>LME A Grade</td>
<td></td>
</tr>
<tr>
<td>Electrodes per bath</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>Cathode dimensions</td>
<td>1.57 x 1 m</td>
<td></td>
</tr>
</tbody>
</table>

The key advantages of the Intec Process cell compared to copper-sulphate electrowinning cells are summarised below:
- The Intec Process copper dendrites are removed in-situ using a wiper mechanism and a conveyor belt. This eliminates the cost of cathode removal and stripping, allowing continuous production;
- Three times the average current density of a sulphate cell is used in the Intec Process, thereby significantly reducing the overall tankhouse footprint. The copper production rate is up to eight times that of a conventional sulphate cell;
- The Intec Process cell can be fed with cuprous (Cu⁺) ions, thereby reducing the overall energy requirements;
- The oxidant (Halex™) generated at the anode is re-used in the leach circuit, whereas the oxygen from the sulphate cell anode is wasted to the atmosphere. This also means that the electrical energy applied to the cell is fully recovered as copper metal and leach reagent.

The copper dendrites are washed and converted to oxygen-free copper wire rod, which attracts a premium of typically 4-8% over LME A grade cathodes. Intec has successfully drawn 8mm wire rod, produced from electrowon copper dendrites, to 0.1mm magnet wire, which meets normal wire standards.

For some projects (typically those of small scale), economic considerations dictate that a cupric leach is preferred. The electrowinning cell can be operated using Cu²⁺ ions, with the only detrimental impact being a higher energy demand.

### 2.3.2 Solvent Extraction of Copper from Halide Solutions

An alternative to the direct production of metallic copper by electrowinning in the Intec Process is the use of solvent extraction to selectively extract the copper into a separate process stream.

Over the last 30-40 years, copper solvent extraction followed by electrowinning has gained a 20% market share of the production methods for copper metal.

Most of the solvent extraction reagents contain oximes and are well developed and optimised to transfer cupric ions (Cu²⁺) from a sulphate system, through the solvent. On the other hand, in the concentrated halide brines used by Intec, copper is complexed as a negative anion such as CuCl₂⁻, CuCl₃⁻, CuCl₄⁻, and CuCl₅⁻, hence other types of reagents must be used.
In circuits where cuprous (Cu\(^{+}\)) is the major form of copper, tri-butyl-phosphate is used. Care must be taken to ensure that the copper is not oxidised and (enclosed) pulsed columns are applied in these circumstances. The entire copper-chloride complex is transferred according to Reaction 15. The stripping solution is copper-depleted catholyte from the halide electrowinning cell.

\[
H_2(CuCl_3) + nTBP \rightarrow nTBP.H_2(CuCl_3)
\]

RXN 15

In circuits where cupric (Cu\(^{2+}\)) is the major form of copper, 7-(4-ethyl-1-methyloctyl)-8-hydroxyquinoline is used. This reagent is capable of loading both cationic and anionic forms of copper as shown in Reactions 16 and 17. The loaded solvent is stripped with water to remove the halide anions, and then with acid to recover the copper cations. Using this mechanism, it is possible to transfer copper from a halide into a sulphate matrix for copper electrowinning or crystallisation of copper sulphate pentahydrate.

\[
2NROH + Cu^{2+} \rightarrow (NRO)_2Cu + 2H^+
\]

RXN 16

\[
2HORNHCl + CuCl_2 \rightarrow (HORNH)_2CuCl_4 + 2Cl^-
\]

RXN 17

### 2.3.3 Copper Oxychloride Precipitation

For small scale projects, the most economical method for recovering copper from a concentrated halide solution is to precipitate copper oxychloride using limestone, as shown in Reaction 18. The copper must be present as the cupric state, as cuprous ions are stable up to a pH of 6-6.5, necessitating the use of more expensive lime.

\[
4CuCl_2 + 3CaCO_3 + 3H_2O \rightarrow 2Cu_2(OH)_3Cl + 3CaCl_2 + 3CO_2
\]

RXN 18

Copper oxychloride is widely used as a fungicide and also competes against copper sulphate pentahydrate as an animal feed supplement. It commands a value of between 85-95% of LME for the contained copper. Unfortunately the niche market limits the applicability of this option to small-scale production.

A convenient method for reprocessing copper oxychloride is to use conventional oxime solvent extraction reagents (e.g. ACORG 5640). The precipitate is releached in acid, with the dissolved chloride limited to 1 M. The cupric cations are loaded onto the solvent and stripped with hydrogen cations. In this fashion the copper can be transferred to a conventional sulphate electrowinning circuit for recovery. This technique is highly applicable to projects where existing sulphate processing infrastructure is available.

### 2.4 By-Product Credit Metals Recovery Options

The process steps required to recover by-product metals such as gold, silver, indium and bismuth can vary significantly, depending on the concentration of the metals in the feedstock and their relative value to any particular project.

Where the by-product contents and/or values are comparatively low, the chosen recovery methods will be simpler, producing lower-grade products at lower operating cost to maximise overall profitability. Conversely, where the by-product contents and/or values are comparatively higher, there is value in using more sophisticated techniques to recover higher-value products, in many cases in metallic form.
As the methodology can vary quite significantly based on the individual project needs, Section 2.4 provides only a rough guide to the process options available for by-product metal recovery.

### 2.4.1 Gold

Gold recovery from Intec Copper Process leach liquors is achieved using activated carbon or ion-exchange resins in packed columns. These columns are contacted with clear leach solution advancing from the cupric thickener, where the oxidation-reduction potential is sufficient to maintain the gold in solution.

The activated carbon can be saturated with gold and then ashed to recover gold metal. Alternatively the loaded activated carbon is stripped using conventional cyanide or thiourea reagents and the eluted gold is electrowon. The eluted carbon is then reactivated as required, and returned to the process. Test results have shown that re-activation is not required for at least five cycles. The latter route is also applicable to ion-exchange resins.

### 2.4.2 Silver

The liquor exiting the gold recovery stage (or directly exiting the leach, if gold recovery is not required) is advanced to another series of columns containing selective silver adsorption resins developed primarily for the Intec Process. The loaded silver is stripped using acid, with the silver precipitated as a chloride for direct sale or smelted to produce silver metal. The barren adsorbent is returned to the process.

For solutions containing cuprous ions, i.e. when a counter-current leach design is used, the silver is recovered using copper amalgamation promoted by trace mercury. A stoichiometric amount of reducing agent is added to the solution, such as copper dendrites from the electrowinning cell, to control the potential of the solution.

### 2.4.3 Indium

Indium in the copper leach processes is recovered directly using ion-exchange resins in packed columns or is precipitated to produce an indium-rich cake for further processing. The feed stream must be depleted of Fe$^{3+}$ and Zn$^{2+}$ ions, which compete for the active sites on the resin. The loaded resin is eluted with acid and the eluted indium is electrowon to produce high purity metal or crystallised to produce indium salts. The eluted resin is recycled to the process.

### 2.4.4 Bismuth

Bismuth recovery in the copper leach processes is very similar to indium recovery, where bismuth is recovered directly using specialty adsorbents in packed columns or is precipitated to produce a bismuth-rich cake for further processing. The loaded adsorbent is eluted with acid and the eluted bismuth is electrowon to produce high purity metal or crystallised to produce bismuth salts. The eluted resin is recycled to the process.
3 Intec Process Advantages

The world’s supply of primary copper is produced by technologies that are solely pyrometallurgical in nature, or solely hydrometallurgical, or more frequently a mixture of the two. This section compares the Intec Process to the most common industrial smelting (pyrometallurgical) and hydrometallurgical processes.

3.1 Intec Process vs. Smelters

The pyrometallurgical treatment processes used in smelters for the production of base metals (generally from sulphide ores) have a number of well-established disadvantages when compared to hydrometallurgical processing:

- High unit capital costs which become economically feasible only at very large scale. As such, smelters tend to be centrally located on rail, road and/or port transport routes, accepting feedstocks from multiple mines, in many cases transporting the feedstocks for thousands of kilometres prior to processing. Smelters are only built at minesites for very large projects;
- High-grade and metal-specific concentrate feeds are required, which tend to detract from the recovery of base metals from the ore into the concentrate (smelter feedstock);
- The handling of many common metallic and other contaminants in base metal concentrates is difficult and either pollutes the air with sulphur dioxide and other contaminants such as arsenic and lead, or incurs the high costs of pollution containment;
- Sulphuric acid is produced as a by-product from sulphur dioxide emission control. Its value is highly variable depending on location and may even be negative.

The Intec Process has significant advantages over existing smelting technology. These advantages are both economic and environmental and include:

- Significantly lower operating and capital costs;
- Smaller scale projects are economically viable;
- Low grade and contaminated concentrates are tolerated;
- No noxious gases are produced; and
- Sulphur is converted from the leachable minerals into its elemental form, from which it may be recovered if required.

3.2 Intec Process vs. Sulphate Hydrometallurgy

Many attempts have been made to overcome the various economic and environmental problems associated with copper smelting, mostly via the development of hydrometallurgical processes in the sulphate medium. These sulphate-based technologies share a number of characteristics which impact on their economic and environmental performance:

- All contain an SX/EW step meaning that their economics can never be better than the economics of the SX/EW step;
- All require a secondary leach step to recover precious metals from their residues (precious metals are insoluble in sulphate systems), which are processed separately at additional cost. This is a significant factor, as over 80% of copper concentrates contain economically recoverable precious metals;
- Cyanidation is required to recover precious metals from residues. This is an important economic and environmental consideration;
- Residues may be expected to contain jarosites which are physically problematic to handle, and are environmentally unstable.

The main sulphate-based copper hydrometallurgy processes that have reached the advanced pilot stage are set out below:

- The Total Pressure Oxidation Process or PLACER Process (ultra high-temperature/pressure oxidation of concentrate followed by SX/EW for copper recovery);
- The Activox Process (ultra fine grinding followed by moderate-temperature/pressure oxidation of concentrate followed by SX/EW for copper recovery);
- The Albion Process (ultra fine grinding followed by atmospheric pressure ferric leach followed by SX/EW for copper recovery);
- BioCOP and Bactech Processes (direct bacterial leaching processes followed by SX/EW for copper recovery);
- The Dynatec Process (high temperature pressure leaching of concentrates with dispersant coal addition followed by SX/EW for copper recovery);
- The CESL Process (high temperature/pressure oxidation leach with added chloride followed by SX/EW for copper recovery);
- AARL/UBC (high temperature/pressure oxidation leach with added surfactants followed by SX/EW for copper recovery); and
- Galvanox (low temperature leach)

Few of these technologies have progressed to commercial-scale application.

As distinct from the above sulphate-based hydrometallurgical processes, the Intec Copper Process as well as the HydroCopper Process and Sumitomo Copper Process are based on halide (mixed chloride/bromide) chemistry. Intec’s unique halide chemistry facilitates the paradigm shift that is essential to the commercially successful transformation of the copper concentrate processing industry economics.

Intec’s advantages over the sulphate-based hydrometallurgical processes variously include:

- Atmospheric-pressure, low-temperature leach conditions
- Low cost materials of construction
- Direct recovery of precious metals
- No requirement for solvent extraction
- No requirement for pure oxygen
- Copper EW from the cuprous (one electron) state rather than the cupric (two electron) state, greatly reducing energy consumption
- Regeneration of the lixiviant at the anode of the EW cell in soluble form for return to the leach circuit rather than the wastage of anodic energy by the bubbling of pure oxygen to the atmosphere in the sulphate system
- Significantly lower operating and capital costs
- Economic viability down to smaller-scale capacity levels
- Production of an environmentally acceptable residue
- Lowest energy consumption
- No liquid effluents.
4 Intec Process Economics

The Intec Process has a considerable range of advantages relative to smelting and other hydrometallurgical processes, of which the most compelling advantage is its low economic cost. This section provides an economic comparison of the Intec Process to other existing and developing copper processing technologies. Additionally, a range of economic models have been prepared to summarise and compare various project scenarios.

4.1 Intec Process Economics vs. Competing Technologies

The economic comparison contained in the below figures is the primarily derived from independent analyses commissioned by Intec over a number of years, plus some of Intec’s enquiries and calculations.

The comparison in Figure 4-1 is based on the development of conceptual mass balances for each of the processes reviewed, from which operating and capital costs were estimated in a 2003 study. This approach ensures a consistent basis for comparison and includes the following key assumptions:

- Plant capacity of 100,000 tpa copper
- Treatment of a 25% copper concentrate feed containing no precious metals
- Power cost of 6.25US¢/kWh.

Intec has then incorporated into this analysis the capital and operating costs of a precious metals recovery circuit for all of the hydrometallurgical processes reviewed. The need for the separate recovery of precious metals by other hydrometallurgical processes is important, as approximately 80% of the world production of copper concentrates contain economically recoverable quantities of precious metals.

The comparison assumes on-site production costs and therefore excludes marketing and freight costs and acid credits, whilst the cost of acid neutralisation is included. It should also be noted that these calculations incorporate an additional step for the melting and casting of the Intec Copper Process dendritic product into ingot, to give a conservative and equal basis for comparison.

![Figure 4-1: Comparison of Operating and Capital costs at 100,000 tpa Copper plant capacity for various process technologies](image-url)
4.2 Intec Process Economic Models

More recent economic models for five Intec Copper Process production options are presented, covering three different production scales (6,000, 20,000 and 50,000 tonnes of copper per annum);

Option 1: Production of Copper Oxychloride
Option 2: Production of Copper Sulphate Pentahydrate
Option 3: Production of Copper metal via a sulphate electrowinning process
Option 4: Production of Copper metal via a chloride cuprous (Cu⁺) electrowinning process
Option 5: Production of Copper metal via a chloride cupric (Cu²⁺) electrowinning process

The following key assumptions have been made to produce these models;
- Copper price of AUD$ 7,000 /tonne
- Discount rate of 10%
- Project life of 10 years
- Concentrate cost not allowed for
- The plant is located in Australia and so Australian reagent, utility and labour rates apply.

It should be noted that, to be conservative, no credit metals such as silver or gold are included in these estimates. Credit metals can greatly increase revenues depending on which process option is selected. Similarly, the integration of the plant into existing SX/EW plants would significantly reduce capital cost for some of these options.

Figure 4-2 provides a graphical means by which process options can be compared at different production scales in terms of their profitability index (project NPV divided by initial capital investment) and operating cost/tonne of produced copper.

Figure 4-2: Comparison of Profitability Index (NPV/CAPEX) versus OPEX for Five Copper Products at 6,000, 20,000 and 50,000 tpa Scales
It can be seen that for small scale production (6,000 tpa), intermediate copper production (copper oxychloride or copper sulphate pentahydrate, Options 1 and 2) or cuprous (Cu⁺) electrowinning would be preferable. The selection of process option would be dependent on market conditions (especially product demand and energy costs) in the respective plant region.

For larger scale production (>20,000 tpa), copper electrowinning becomes preferable. It should be noted that although the precipitation of salts at large scale still offers good profitability indices, global demand for those products is limited and hence the revenue figures may not be as easily achievable. Large-scale copper salt production has therefore not been included in Figure 4-2. At 20,000 tpa scale, the profitability index for both Intec Process copper metal producing options is at or greater than 2.8. At 50,000 tpa scale, the index is 4.7 – 5.6, and this is where the economic benefits of large scale operations are realised.
5 Intec Process Environmental Advantages

There are numerous environmental advantages to the Intec Process when compared to competing pyrometallurgical and hydrometallurgical technologies. Some of these have already been explored, such as the successful treatment of arsenic containing feedstocks and the environmental stability of the iron residues. This section details a life cycle analysis of the Intec Copper Process in comparison to a number of competing copper processing technologies.

5.1 Life Cycle Analysis

Intec commissioned a Life Cycle Analysis (LCA) of the Intec Copper Process in 2001. This study was conducted by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) using published data for the competing technologies, as well as information provided by Intec Ltd for the Intec Process.

The base case of the CSIRO LCA compared the Intec Copper Process with flash smelting, four pressure oxidation hydrometallurgical processes, and two biohydrometallurgical processes. Using a system boundary incorporating mining, concentrate production, and metal production & refining, the boundary for all processes was an equivalent ‘cradle-to-gate’ for copper metal production. The initial production of a 25% copper concentrate (30% S, 100g/t Ag, 10g/t Au) as uniform feedstock to the process was assumed, with the electricity used by the processes being generated from black coal at 35% efficiency.

As an Intec Copper Process plant would most likely be located at a mine site to optimise the advantages associated with the Process’ flexibility of scale, improved ore-to-metal recoveries through the production of lower grade concentrates at the mill, and improved economics through avoiding smelter charges and penalties, it was assumed that no transport would be required for the Intec Copper Process. The same assumption was used for the other hydrometallurgical processes. It is worth noting, however, that the Intec Process benefits of most of these optimisation measures (particularly the higher ore-to-metal recoveries) were excluded from the analysis in the common assumption of the production of a 25% copper concentrate.

Given that approximately half of the world’s copper production occurs at integrated smelters (presumably involving minimal transport of concentrate), while the other half is traded on the custom market (presumably involving long transport distances including road or rail and possibly ship), a conservative assumption of 500km transport by rail was assumed for smelting in the base case.

After collating all process information from the published data, the figures were sent by the CSIRO to the appropriate companies for review, and comments or changes incorporated where applicable. Within the context of the assumptions used for the LCA, the seven processes were compared for Total Energy Consumption (TEC, MJ/kg-Cu), Global Warming Potential (GWP, kg-CO₂(eq)/kg-Cu) and Acidification Potential (AP, kg-SO₂(eq)/kg-Cu).

The cradle-to-gate system boundary applied encountered one problem in that the Intec Copper Process produces LME Grade A copper in dendritic form, while the other hydrometallurgical and smelting processes considered produce copper in pure cathode form. It is unlikely that the Intec Copper Process product would be cast into ingot without any form of value-adding. Rather, the product would most likely be melted and cast into product forms from the molten state. Either way, this leaves a disparity between the products being compared. As no resolution for this was possible, the conservative assumption that the Intec Copper Process product would be melted and cast into ingot was used.
As shown in Figure 5-1, the base case conclusion from the CSIRO LCA was that the total energy requirement for the Intec Copper Process is 36% lower than the average for pressure oxidation hydrometallurgical processes and 41% lower than the average for biological processes, but 5.9% higher than that for smelting when using black coal. However, using hydro to generate electricity, the Intec Process impact was lower than that of smelting. The differences are even more marked for Global Warming Potential (Figure 5-1).

With respect to the differences between the Intec Copper Process and flash smelting, the result is similar to expectations, because a significant proportion of the energy obtained in smelting is obtained from the burning of sulphur minerals instead of carbon fuels to produce the smelters’ energy. This creates large amounts of sulphur dioxide, which if uncontrolled would yield significant acid rain, but reduces the apparent total energy consumption by smelters. Even incorporating smelter gas controls, the production of this sulphur dioxide is the reason for the marked advantage for the Intec Copper Process for Acidification Potential (Figure 5-2). Effectively, smelters trade one form of environmental impact (GWP) for another (AP).

While both processes use electricity, the largest single source of electricity consumption associated with all hydrometallurgical processes is the electrowinning of metals from solution. As may be seen in Figure 5-1, the effect of changing the fuel used for power generation changes the ratios for Total Energy Consumption and GWP. Using either natural gas or hydroelectricity instead of black coal, the Intec Copper Process maintains and extends its advantages over pressure oxidation and biological hydrometallurgical processes, while reducing the impact versus flash smelting. Using hydroelectric power, the Intec Copper Process offers the lowest impacts for Total Energy Consumption, Global Warming Potential and Acidification Potential under the set of assumptions employed by the CSIRO LCA.
The advantages of the Intec Copper Process over smelting become even more pronounced when lower concentrate grades are considered. Noting that flash smelting may not even be economic at lower grades, the total energy consumption associated with Intec Copper Process and flash smelting treating a 20% concentrate was calculated to be almost identical at 51.4MJ/kg-Cu and 51.5MJ/kg-Cu, respectively. At 15% copper in the concentrate, where few if any smelters could operate economically, the results were 52.1 and 58.5MJ/kg-Cu, respectively. These results include the conservative assumptions of the melting of the Intec Copper product and casting as ingot, and the use of black coal power generation.

Given that higher metal recoveries may often be obtained at the mill by the production of lower grade concentrates, and given the greater flexibility of scale offered by the Intec Copper Process, the Process offers several notable advantages over smelting to the miner:

- Lower TEC, GWP and AP than smelting when using either lower grade concentrates or alternate fuel sources to black coal for power generation;
- Fewer environmental impacts associated with the loss of copper minerals to the mill tailings;
- Greater project returns associated with higher ore-metal recoveries;
- Greater resource utilisation associated with the ability to lower the ore cutoff grades feeding the mill. They may also extend mine life; and
- By operating at the mine site, the Intec Copper Process offers smaller mines the opportunity to contain the value associated with metal production from concentrate within the mine gate, rather than passing it on to smelters.