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INNOVATION, SUSTAINABILITY AND THE FUTURE OF METALS EXTRACTION

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ABSTRACT

The metals extraction industry is facing arguably its greatest-ever challenges with the need to demonstrate “sustainability” in the face of dwindling reserves and grades, increased restrictive legislation and all combined with increasing costs. Notwithstanding the current downturn in metals demand and prices, in order to be able to meet the projected demand over the next couple of decades, it is argued that a paradigm-shift in the way that we carry out metals extraction is needed. Mining, as opposed to processing, generally represents the main costs associated with any metals extraction project, and in order to even entertain the idea of being “sustainable” in the face of being essentially non-renewable, the industry can no longer afford to throw away up to 99% of the material it spends vast sums on digging up out the ground. Additionally, more often than not, this material that is discarded is also toxic, and cannot, therefore, be returned whence it came.

It is shown that the industry has not been averse to investigating new and novel processes, with much research having been carried out in the 1970s and onward. Unfortunately, very few of these processes even reached the pilot stage, such that there is now an inherent distrust of new technology, especially those in a chloride medium. However, it is argued that it will only be by adopting new, even novel, all-encompassing processes, that far more value can be recovered from a tonne of ore than is currently being achieved, and that the industry can claim to be “sustainable.” Using, as an example, a nickel laterite ore containing 1.2% Ni, and producing 50 ktonne/annum Ni metal, it is shown that revenues approaching an additional 50% could be generated simply by recovering the associated iron, aluminium and magnesium in a marketable form. There is sufficient iron and aluminium for a stand-alone steel mini-mill and aluminium smelter.

The concentrated chloride processing route, whilst not new, has been developed and refined over the past decade with these objectives, amongst others, in mind. The latest stage of pilot plant developments for various processes is briefly presented.

Keywords: Sustainability, metals extraction, nickel, laterite, iron, aluminium, magnesium, chloride

INTRODUCTION

In 1556, in the De Re Metallica, the first great book written about mining and originally published the year after his death, Georgius Agricola described the environmental issues associated with mining and mineral extraction(1). He wrote:

> "*… further, when the ores are washed, the water used poisons the brooks and streams and either destroys the fish or drives them away … thus it is said, it is clear to all that there is greater detriment from mining than the values of the metals which the mining produces.*"

Agricola spent the latter years of his life in Chemnitz, Saxony, which was at the centre of the great sixteenth century mining district of the Erzgebirge. He was thus well-placed to observe and comment upon the inherent problems associated with the extraction of metals.

However, it was not until half a century ago, that the metals extraction industry really began to realize, and more importantly, accept, that the principal side effect of recovering metals, namely the vast amounts of wastes produced and the general environmental damage caused by not only by these wastes, but also the failure to capture and deal with the off-gases from smelting, was a significant problem, and one that would have to be dealt with. Despite the many advances in smelting that were occurring at this time, it was widely believed that the answer to the environmental dilemma lay in embracing hydrometallurgy.

In October of 1971, the Institution of Mining and Metallurgy (IMM, London, UK, as it was then known) held the second in a series of what it hoped would become industry standard metals extraction conferences(2). It is instructive that, although the conference was entitled "Advances in Extractive Metallurgy and Refining," of the 30 papers presented, only four were on hydrometallurgy, none were on electrolytic refining and certainly, there were none specifically on environmental aspects. One of these hydrometallurgical papers, nevertheless, has become iconic with the passing of time, in that it described the development in Zambia of the world's largest tailings re-treatment plant, combined with what is still one the largest copper solvent extraction plants(3). Despite this, the main focus of the conference was on the new emerging continuous copper smelting processes, especially WORCRA from Australia and Noranda from Canada. Although Glencore (as Noranda now is) still operates a Noranda Reactor (in matte mode only, and not as the intended continuous process) at the Horne Smelter in Quebec, continuous copper smelting was never a success.

The third (and last) conference in this series was held in 1977, under the title "Advances in Extractive Metallurgy 1977"(4). Again 30 papers were presented, with the breakdown this time seeing an increase to seven purely hydrometallurgical papers, two mixed pyro-hydro papers, and one on mineral processing, but again, there were no papers dealing with environmental considerations. However, once more there was a Zambian paper dealing with the retreatment of a waste, this time one of the smelter slag dumps(5), a process which was subsequently implemented, albeit twenty-five years later(6).

Notwithstanding this, however, one of the session chairs at the 1971 conference, the late and renowned Australian pyrometallurgist, T.R.A. (Ron) Davey, was moved to opine that, echoing President Kennedy's famous moon speech, "*we shall all be in water by the end of the decade*"(7). Ron Davey, like many others, had become acutely aware that the metals extraction industry faced considerable and mounting difficulties over its practices, particularly in connection with energy usage and environmental challenges. Naively, and also like many others at that time, he believed that the answers lay in embracing hydrometallurgy, since there was some precedent for such optimism. Sherritt Gordon (as it was then known) were the pioneers in this sense with the ammonia leach/hydrogen reduction process for nickel-cobalt feeds at Fort Saskatchewan(8,9,10), followed by Falconbridge (as this part of Glencore then was) with its chloride-based circuit at Falconbridge in Norway(11,12,13,14).

It is fair to say that with the above background, the industry then embarked wholeheartedly into developing what it hoped would be cleaner, more efficient and environmentally-friendly processes. Indeed, it was noted at Noranda at the time that they could NOT afford not to be involved in developing their own process version, and similar sentiments were expressed by almost all of the major companies involved. However, as noted later, virtually all of this effort did not significantly affect the way in which the industry carried on its business.

Twenty years after the 1971 IMM Conference, Alex Balogh, then the CEO of Noranda-Falconbridge, in addressing a business conference in Toronto, stated that(15)

> "*... practices that were acceptable even ten years ago are simply not tolerated today. As a result, we are designing our new mines (and processing plants) in radically new ways.*"

The **intent** has clearly been there, but in reality, relatively little has changed, the industry still creates vast amounts of toxic wastes, with very, very little of it being re-processed, despite improved extraction techniques and sophisticated process controls, and there is no real indication of any desire to extract additional value from complex feeds.

HYDROMETALLURGICAL PROCESSES FOR SULPHIDE-BASED FEEDS

The main advantages claimed for hydrometallurgical processing were lower energy costs, zero or minimal air pollution and the ability to treat polymetallic feeds. These claims remain largely true today, especially in terms of cobalt recovery with nickeliferous feeds(16), although the claim to lower energy costs was vigorously disputed, notably by Herbert Kellogg, and especially if electrowinning was part of the flowsheet(17,18). The obvious disadvantages, particularly from environmental and sustainability viewpoints, are the high volumes of generally toxic, and often slimy, leach residue, the word toxic here encompassing both heavy metal toxicity and acid generation potential. A further disadvantage is that any precious metals present in the concentrate have been very difficult, if not impossible, to recover economically from the leach residues, although the Platsol™ and CESL processes referred to below have since demonstrated an ability to overcome this.

Nevertheless, beginning in the 1970s and continuing into early 1980s, there was a great deal of almost evangelical interest and enthusiasm in, and research into, developing hydrometallurgical processes for the treatment of (primarily) copper sulphide concentrates(19,20,21,22). An astonishing number of different processes were developed, demonstrating considerable innovation and so-called "out of the box" thinking, with most emphasis being on chloride-based processes although several sulphate-based circuits were conceived, together with one notable ammonia-based flowsheet, Anaconda's Arbiter Plant(23). There were also some interesting investigations using mixed lixiviants.

Of these early attempts, only Duval's CLEAR (Copper (chloride) Leach Electrowin And Regeneration) Process(24,25,26,27,28,29) and the Arbiter Process mentioned above attained commercial operation. Arbiter operated for just over three years from 1970, and CLEAR from 1976 until 1982, with both being shut down for economic reasons. Despite laudable objectives, neither really achieved the advantages originally claimed and expected, and on which the building of the plants was based. Habashi has briefly summarised the operations of these and other "nearly" processes(30).

The Cyprus CYMET Process(31,32,33,34,35,36) attained a pilot operation at 45 kg/h, but none of the others, those of Minemet Recherche (Imetal) in France(37,38,39), Dextec in Australia(40,41,42,43,44,45), Elkem in Norway(46,47), the USBM Process (48,49,50,51), the Canadian Great Central Mines Process (52,53,54), Phelps Dodge(55), and UBC/Cominco(56), with the exception of Dextec which transmogrified itself into the Intec Process(57,58,59,60,61) but now has gone the way of all the others, seem to have progressed at all. Although the literature contains many references to ferric and cupric chloride leaching of chalcopyrite concentrates(22), of which the studies by Dutrizac(62,63), Majima et al.(64), and Holdich and Broadbent(65) are of interest, none of the processes really overcame the difficulties associated with precious metals recovery, electrowinning of copper from a chloride medium (i.e. trying to take advantage of a one-electron rather two-electron change, thus reducing power consumption), and the effective recycle of lixiviant, whether ferric or cupric.

Coincident with the tailing off of this initial enthusiasm, the nationally-funded research laboratories of the USBM (United States Bureau of Mines) and Warren Spring in the UK were closed permanently, whilst Canmet, in Canada and, to a lesser extent Mintek in South Africa, were required to exist on a "cost-recovery" basis. The Ontario Research Foundation (ORF) and BC Research in Canada were privatised. The shining light was CSIRO/Parker Centre in Australia, but even this is now under considerable threat of downsizing, leaving essentially only BGRIMM in China. And, it was not only the nationally-funded laboratories that were hit, with a number of major companies shutting their own research laboratories and others (largely unsuccessfully) trying to off-load them as viable stand-alone entities.

Despite these setbacks, and competing very much with the newer and more modern smelting processes, which were now often combined with sulphuric acid plants for the capture of the SO_2 off-gas, the late 1980s and early 1990s saw renewed interest in chloride-based processes, primarily for the treatment of complex base metal sulphide feeds which were not amenable to smelting. Those of particular interest, in addition to the advent of the Intec Process noted above, were the CANMET FCL (Ferric Chloride Leach) Process(66) the Cuprex process of ICI and Tecnicas Reunidas in Spain (67,68), otherwise known as CMEP or later, Cuzclor(69), and the CENIM-LNETI Process, developed in Portugal, and which interestingly employs an oxidising leach in a strong ammonium chloride solution(70). However, to date, once again, none of these appears to have reached commercialisation. Rice has recently summarised substantial chloride-based work carried out over many years at the University of Leeds in the UK(71). Whilst the work was primarily aimed at laterite leach solutions, the data are largely equally relevant to solutions derived from sulphide sources.

The past few years saw continued development of the Intec Process referred to above, which used a mixed bromine/chlorine oxidant, $BrCl_2^-$, denoted Halex™, although this now seems to have failed, and Outokumpu's HydroCopper™ Process, which makes novel use of a chlor-alkali cell(72,73,74,75). Also being promoted at the present time is chloride-assisted sulphate pressure leaching, originally developed as Noranda's Antlerite Process in the 1970s(76), a variation and modification of which is the CESL Process(77,78,79,80,81,82,83), and more recently the basis of the process being used by Vale for Voisey's Bay in Newfoundland(84). A similar process, although operating at higher temperatures, is Platsol™(85), developed for the Northmet Property in Minnesota, which was designed specifically to be able to recover the contained precious metals. Apart from Vale with intended start-up in Long Harbour, Newfoundland, none of the other processes discussed above seem to have progressed to full a fully-commercial operation.

On the purely sulphate side, which does not, and really cannot due to the inherent nature of sulphate chemistry, address any of the issues referred to in the following section, the Phelps Dodge Copper Leach Process(86,87,88,89) operating at Bagdad, Arizona in the US achieved successful commercial operation. This was designed for a site-specific combination of oxide and sulphide, with the acid generated in the pressure leach being used to leach the oxide copper. Low pressure leach processes combined with ultra-fine grinding have also been promoted, notably the Activox™ Process originally of Lionore(90), which attained demonstration Plant stage at Tati in Botswana, which was subsequently acquired and then apparently abandoned by Norilsk. A similar process is Albion™, originally developed by Glencore (MIM/Xstrata) in 1994 which has been commercialised(91), as has the Sepon Copper Process(92,93). More recently, the Galvanox™ Process, developed at UBC, has received some attention(94).

There have also been attempts to develop nitrate-based circuits(95), and notably the Nitrox or Redox Process(96,97). The process was intended to be piloted at Bakyrchyk Gold in Kazakhstan [98], but was never successful(99). The use of nitrates for refractory gold has been summarised by Li(99), and it appears that the process may now be being operated in China. Certainly, nitrate processing has never been successfully applied to base metals. Nitric acid, being a very powerful oxidant, is inherently unsafe, especially in the presence of reductants such as metal sulphides, and as such, is prone to "runaway" reactions. Controlling and dealing with such runaways is completely counter-intuitive, which is where the safety issues arise.

Nevertheless, the use of nitric acid is receiving renewed interest, notably by Direct Nickel for the processing of laterites(100,101,102). The process has been piloted in Perth, but as of the first quarter of 2016, operations are on hold pending an upturn in the resource sector. It will be interesting to see how this develops, since no large-scale nitric acid-based commercial plant (other than electrolytic silver refineries) has ever been built.

Finally, mention should be made of bacterial leaching for base metals. Whilst such has seen some measure of success in gold plants, attempts to apply the technology to base metals have largely been unsuccessful until very recently. An initial pilot project in Chile, comprising a Joint Venture between BHPBilliton and Codelco, known as Alliance Copper, ultimately resulted in the building of a 20,000 tpa copper(103). However, the project was terminated in October 2006, having not achieved its objectives. Similar processes were mooted for nickel and zinc with similar results, but much more recently, there have been two successful projects implemented for nickel. Of these, Mondo Minerals Nickel in Finland has now attained commercial operation(104,105), whilst Western Areas in Australia has piloted a Bioheap® process essentially to remove arsenic from a nickel sulphide waste stream(106,107). This project has reached the Engineering and Procurement stage, but no final decision has yet been taken to proceed to commercial operation.

As noted above, this represents an astonishing amount of research and development, for what has to be said very little, if any, profitable return. One of the keynote speeches of the CIM/TMS/SME 2003 Hydrometallurgy Conference considered why new hydrometallurgical processes failed(108). Four points were highlighted, these being:

1. If any pilot-scale testing was conducted, it was for the purpose of generating product, not confirming process parameters.
2. Equipment was downsized or design criteria were made less conservative in response to projected cost overruns.
3. Process flowsheets were unusually complex with prototype equipment in two or more critical unit operations.
4. Process chemistry was misunderstood, or not completely understood.

It is our experience that points 1 and 4 are generally the most prevalent, and more especially, the fourth, regarding the aspects of both process chemistry and physical chemistry.

In terms of the continued development of hydrometallurgical treatment for sulphidic copper concentrates, the keynote paper by SNC Lavalin at this conference presents a well-reasoned assessment of when to use pyrometallurgy, when to use to use hydrometallurgy, or when to use a combination thereof(109). Many of the arguments presented apply equally to other sulphide-based metals such as nickel and cobalt.

ISSUES WITH CURRENT EXTRACTIVE METALLURGICAL PRACTICE

Since the beginning of time, we have dug up rocks, extracted only what was needed and discarded the rest. Indeed, the Ages of Human History are characterized as the Stone Age, the Bronze Age and the Iron Age, all of which are mining-related reflecting the fact that our societies have been heavily dependent upon what is in the ground. Modern times could similarly be characterized as the Electronic or Digital Age, one which again depends very heavily on metals, albeit this time minor and rare metals as opposed to the mass-production and high volumes of former times.

In the recovery of most metals and industrial minerals, it is the actual cost of mining the rock which is by far the largest cost factor. Exceptions to this generality may be found in large-scale open pit operations, but, especially for underground mines, the cost of mining is significant. Yet, the industry is content with this. It is content to mine a tonne of ore, to recover a few grams of gold or kilograms of copper or nickel, and throw the remainder back, often then laced with toxic chemicals such as cyanide. One of, if not the major, “buzzwords” of modern times is “sustainability.” Quite how this is defined in the context of a non-renewable resource is not clear, but, clearly, current mining practice is not only not “sustainable” but it is also highly inefficient and wasteful.

A New Mindset is Required

Until relatively recently, the economics of many mining projects were estimated only on the basis of the main metal being recovered. For various reasons, by-product credits were rarely included as somehow tainting the purity of the main metal. Certainly efforts to include metals such as iron, magnesium and aluminium as by-products in the recovery of base metals were never considered, with the result that there are vast, often toxic, tailings dumps around the world where these materials are deposited. The reasons for this were quite valid, in that iron residues from conventional base and light metal processing are not suitable for ironmaking and any residues containing aluminium are simply not suitable for processing through a Bayer plant.

However, given the actual costs of mining itself, and that large, rich orebodies are no longer being found, then it surely makes both economic and sustainable sense to maximize the recovery of ALL metals that have value. To illustrate this point, consider a hypothetical nickel laterite, with a composition of 1.2% Ni, 0.1% Co, 5% Al, 15% Mg, 30% Fe is processed with 90% recovery of Ni, Co and Fe, and 75% recovery of Al and Mg. Taking prices of \$5/lb for Ni, \$10/lb for Co, \$0.2/lb for Al_2O_3, \$40/tonne for Fe_2O_3 and \$50/tonne for MgO, the following revenues are generated for a plant nominally producing 50,000 tonnes of LME grade Ni metal:

- Ni - \$550 million
- Co - \$90 million

- Al_2O_3 - $150 million (350,000 tonnes)
- Fe_2O_3 – $70 million (1.8 million tonnes)
- MgO - $30 million (610,000 tonnes)

By this analysis, the revenues of the project can be increased significantly against those generated simply by considering nickel (and cobalt). Furthermore, there are additional benefits in that there are close to 2 million tonnes of residues (equivalent to approximately 50% of the material originally mined) that will not have to be disposed of and monitored. It should, perhaps however, be noted that in this context, current prices are not really indicative of how a mining project might perform, since it requires a number of years to bring one to fruition, and it might be more indicative to take long-term average prices(110). Furthermore, there is always a premium for high-grade hematite, so that the revenues to be derived there are probably significantly understated. However, in the context of the illustration, the actual prices are irrelevant, since the objective is simply to demonstrate the point that these values have been mined but are not being realized.

The standard arguments against this being achievable are:

1. The technology to achieve these recoveries in sufficiently pure form does not exist.
2. If it did exist, then it would be too expensive and difficult to implement.
3. The existing markets could not absorb such tonnages.

None of these are valid. The most persuasive, the first, is no longer true, as will be demonstrated later in this paper. The second is somewhat facile, since equipment and circuits have to be built and operated to deal with the metals anyway in addition to providing much larger residue disposal areas, which in many cases, will have to be managed in perpetuity, and ultimately revert to the control of the state, i.e. the collective individual taxpayer. The third is simply not true, and the amounts of iron and aluminium, in particular, are small compared to those processed by the respective primary industries. Nevertheless, in the case of iron and aluminium, the amounts generated from the hypothetical laterite project are sufficient to operate a stand-alone steel mini-mill and aluminium smelter. This ought to be attractive in an established and diverse mining area such as Western Australia. There is clearly sufficient aluminium associated with the WA laterites to sustain the existing aluminium smelters, and if this were to be recovered in a usable form, then the need to import bauxite disappears.

The question then is how to encourage the mining and metals extraction industry to embrace what is essentially a quantum change in how it goes about its business, and at the same time overcome the negative perceptions created in the past due to the many failed processing routes. The Canadian Mining Industry has established what it calls the Canadian Mining Innovation Council (CMIC)(111). This is

> "*a national non-profit organization that coordinates and develops research development and innovation (RDI) projects and programs in response to* ***life of mine*** *challenges defined by its industry members*."

Its most recent and very laudable initiative is

> "*developing innovation priorities that will lead to significant reductions in mining waste in the next 5 years and move towards net zero waste in mining and mineral processing in 10-20 years*."

Unfortunately, the most obvious source of mining waste, derived from extractive processing and specifically as indicated above, has not, at the present time, been included in the initial methodology to achieve this. It is, nevertheless, an important step in demonstrating willingness.

It should not be construed, however, that although the industry has a well-deserved image of being slow and conservative, and despite the many failures in the past alluded to above, it is totally averse to change and innovation. There have been some exciting and innovative processes developed since the end of WW2, notably:

- Pressure leach
  - Sherritt Ammonia for Ni, Co, Cu

  - Zinc
  - Refractory Gold
  - Laterites (this has really not been proven yet as being generally viable)
- Copper SX in various forms
- Falconbridge Chlorine Leach Process
- CIP/CIL for gold and silver

All of these, whilst in themselves highly commendable and successful, have not really addressed the basic issues confronting the industry today, namely sustainability and environmental liability. It is considered, therefore, that the industry needs to completely change its mindset and how it operates if it is to remain both competitive and at the same time eliminate environmental liability AND be "sustainable."

In this context, therefore, it is believed that re-visiting chloride processing has merit. We have developed and refined the parameters involved with the objectives discussed above in mind to the extent that it can be considered a viable option, and in particular, addressed Point 4 mentioned by Halbe above(108).

MODERN CHLORIDE PROCESSING

Despite the track record of "non-success" of the many chloride-based processes for sulphide feeds, in particular, there remain many compelling reasons why the application of chloride chemistry can result not only in improved processing, but can also contribute greatly to achieving sustainability as far as such is possible when dealing with a non-renewable resource. It is not as though chloride-based plants have been completely unsuccessful. As noted above, Glencore (formerly Falconbridge) has operated a chloride process for many years at its nickel-cobalt refinery in Kristiansand, Norway, which was initially a hydrochloric acid leach, but more lately a chlorine leach(11,12,13,14). Noranda (as it then was) operated the Brenda Leach Process, which employed a high temperature (105-110°C), high-strength chloride (30% $CaCl_2$+NaCl+HCl) atmospheric leach of copper-molybdenum concentrates until the mine shut down in the 1990s(112). The process essentially leached out all of the copper, lead and calcium from molybdenum concentrates, and the only real factor of concern was to maintain the lagging on the piping in winter to prevent the high strength brine from cooling and crystallizing(113).

Some of the advantages that have been already demonstrated by chloride processing(114) are discussed in the following paragraphs. Essentially, most of the advantages that were expected from the use of chloride with the processes developed in the 1970s are still applicable, the only difference being in the means used to achieve them.

Leaching and Intrinsic Energy Content of Sulphides

Energy can be substantially recovered, especially if the feed contains appreciable levels of pyrrhotite(115). This is equally true for sulphate leaching but the advantage that chloride has is that the acid can be recovered and recycled (see iron below). Generally speaking, chloride circuits can be operated at atmospheric pressures, and are more readily adjusted to ensure that the sulphide sulphur either ends up as H_2S gas, or elemental. Generation of H_2S allows for production of elemental sulphur or sulphuric acid, recovery of the intrinsic energy, and also a convenient separation from the leach residue.

Chloride circuits, and particularly concentrated chloride circuits, are more aggressive than their sulphate counterparts. This has the advantage that higher metal recovery can be achieved, along with a residue that is often easier to filter and that is lower volume and less prone to metal/acid leaching into the environment. Indeed, most leach residues are predominantly benign alumino-silicate gangue.

Iron and Hydrochloric Acid

Iron is the major contaminant in virtually every hydrometallurgical processing circuit, and has been deemed worthy of four International Conferences devoted entirely to its control and disposal. Sulphate chemistry is such that iron has to be precipitated via the use of some form of a base, generating large volumes of residues, whether they be jarosite, goethite, hematite or “ferric hydroxide.” However, chloride chemistry affords the possibility of not only recovering the associated acid for re-use, but also of generating a marketable hematite product. At the very worst, this hematite is easy to filter, has a low volume and is environmentally benign.

Aluminium and Magnesium

Because of the highly aggressive nature of the chloride leaching operation, both of these metals tend to report to the resultant leach filtrate in significant concentrations. During acid recovery through hydrolysis of the iron chloride, the aluminium reports virtually 100% along with the hematite. However, the different crystal structures of the two oxides results in discrete compounds, such that the aluminium can be easily separated from the hematite.

Magnesium, on the other hand, remains in the liquid phase as long as either iron or aluminium is present, thus affording an efficient and simple separation. It can be recovered in a subsequent hydrolysis step as its oxychloride, which can be calcined to magnesia.

Current State of Development

Considerable development work has been undertaken on the chloride-based process over the past decade. At the present time, a major pilot plant testing program is planned for later in 2016 in Canada, treating the Barrambie titaniferous magnetite of Neometals from Western Australia. Apart from the recovery of titanium dioxide, the major goal of the pilot operation will be to conclusively demonstrate the acid recovery circuit, and show that any problems previously reported with this unit operation(116) have been overcome. The pilot plant is intended to be multi-functional, with additional campaigns scheduled for treating a nickel laterite and electric arc furnace dust.

DISCUSSION AND CONCLUSIONS

This paper has attempted to demonstrate that, despite much effort over the last half-century, the mining and metals extraction industry needs a paradigm shift in the way it goes about its business. The industry has to become much more sustainable than it currently is, in the sense that any non-renewable resource can be considered to be sustainable. We can no longer mine vast tonnages and then return most of this to tailings dumps, often in a toxic state. Using a hypothetical nickel laterite as an example, it is shown that by recovering the iron, aluminium and magnesium components of the ore, all of which have to be dealt with anyway, not only can the potential revenues from the feed can be increased by 40-50% or more, but the environmental liability is considered reduced.

It is further shown that by adopting chloride processing, it is possible to at least achieve some of these objectives, in the sense that all of iron, aluminium and magnesium are potentially recoverable in a marketable form. That is not to say that existing plants and processes have to be abandoned, or even retro-fitted, because that is simply not possible, but the mindset should be that new projects are designed with the above objectives in mind, and much more effort should be placed on re-treating old tailings dumps, many of which contain significant, recoverable metal values.

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