

**TRIPLE BOTTOM LINE THINKING FOR A HIGH ARSENIC BEARING
COPPER-GOLD PROJECT IN NORTHERN PERU:
ASSESSING THE VIABILITY OF AN INTEGRATED MINE, MILL, AND
HYDROMETALLURGICAL REFINERY**

by

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Abstract

Growth in global urbanization, industrialization and infrastructure expansions will require the development of non-traditional copper resources such as those containing high arsenic to meet the demand for future mine supply. Arsenic levels are rising in current and future mines in resource rich countries such as Peru. Conventional smelting operations cannot accept concentrates high in arsenic ($>0.5\%$) due to process limitations and tightening environmental restrictions. Alternative refining technologies are required to process high arsenic bearing concentrates. Teck Resource Limited's CESL developed pressure hydrometallurgical technology is capable of treating high arsenic bearing sulphide concentrates. Recognizing the broader cornerstones of sustainable development, Triple Bottom Line (TBL) thinking provides a holistic way of understanding a projects' performance with respect to potential financial, social and environmental outcomes. This paper applies a simple TBL framework to assess the viability of an integrated mine, mill, and CESL hydrometallurgical refinery operation for a hypothetical high arsenic bearing copper-gold deposit located in Northern Peru.

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1: Introduction

Global population growth coupled with increased wealth and a desire amongst developing economies to achieve a higher standard of living has resulted in a significant demand for industrial metals such as copper (Norgate and Rankin, 2002, p.1-2; Prior *et al.*, 2010, p.1-2). Despite increased recycling and efforts to reduce the amount of materials used in economic goods (i.e. dematerialization); the demand for new mine supply is expected to be strong for decades to come (Norgate and Rankin, 2002, p.2; Norgate and Haque, 2010, pg. 266). As a result, the source and range of ore deposits in future copper projects will likely be much different from past projects, which are often classified to as ‘conventional’ ore deposits (Amira International, 2004, p.4). This is largely due to the ongoing exhaustion of higher-grade quality ores, which preferably are exploited first (Norgate and Jahanshahi, 2010, p.65). These preferred ore deposits are typically free from significant deleterious impurity elements (e.g. arsenic, antimony, bismuth, mercury, fluorine, and uranium). As well, clean, high-grade ores are easier to mine, and process into marketable concentrates (Amira International, 2004, p.4). In contrast, several of today’s undeveloped resources (i.e. Greenfield’s) are lower-grade, bearing complex mineralogy, and have higher levels of deleterious impurity elements such as arsenic making them difficult to mine and process through to marketable concentrates to smelters (Bruckard *et al.*, 2010, p. 1167; Chen *et al.*, 2010, p.1175; Prior *et al.*, 2010, p.5). These deposits are often referred to as ‘challenged’ or ‘non-traditional’. On top of the challenge posed by lower grades and quality ores, mineral explorers and miners are moving to more remote regions (Deloitte 2011, p.5) with less developed infrastructure and easy access to key resources such as water and human capital. Projects that are remote require the build-up of significant infrastructure and with that, greater socio-economic contributions from mining companies and local governments (Superneau, April 2010, p.12; Stratos Inc. 2008, p.18). The resulting development costs of these projects will be expectedly higher and potentially require new innovative mining and refining technologies to bring them into production (Amira International, 2004, p.4; Norgate and Jahanshahi, 2010, p.65; CRU International September 2009, p.3; Prior *et al.*, 2010, p.5).

The growing need to increase mine supply from primary copper resources in a relatively short period to meet current demand has drawn significant industry attention to the concept of sustainable development. Sustainable development has been defined as: development that meets

the needs of the present generation without compromising the ability of future generations to meet their own needs (Lenzen *et al.*, 2006, p.3; Norgate and Rankin, 2002, p.2). This concept incorporates the commonly referred to ‘Triple Bottom Line’ (TBL) values of positive environmental contributions, social needs, and financial benefits (Esvelt and Karamysheva, 2006, p.6; Norgate and Rankin, 2002, p.2). One of the more recent and growing challenges facing mining and smelting companies will be the sustainable development of high arsenic bearing copper deposits (Ferron and Wang, 2003, p.1) in copper rich countries such as Peru. Despite its wealth of copper resources, many of the copper projects in Peru contain high levels of arsenic sulphide minerals, such as enargite (Cu_3AsS_4). Unfortunately, the presence of significant amounts of enargite among such copper deposits can result in a relatively high arsenic content reporting to the final concentrates, substantially reducing its economic value and marketability to smelters (Baxter and Scriba, 2010, p. 1784; Milhajlovic *et al.*, 2007, p. 26).

Elevated levels of arsenic in concentrates present a challenging metallurgical problem for conventional smelting-converting and electro-refining technology, which is the standard in primary copper metal production (Baxter and Scriba, 2010, p. 1783; Dreisinger, 2005, p.3; Mayhew *et al.*, 2010, p.1983). Only a few copper smelters globally (e.g. Tsumeb, in Namibia) offer to treat concentrates with high levels of enargite, and most copper smelters limit their arsenic inputs for environmental reasons (Brook Hunt Global Copper Concentrate and Blister/Anode Markets, 2010, p.194; Peacey *et al.*, 2010, p.1035). The inability of smelters to treat copper concentrate with higher levels of arsenic will force the copper industry to consider innovative alternative processing routes such as hydrometallurgical technology (i.e. pressure concentrate leaching), which can be integrated with an operating mine (Baxter and Scriba, 2010, p.1784; Brook Hunt Global Copper Concentrate and Blister/Anode Markets, 2010, p.129). Unlike the smelting process, pressure hydrometallurgy (i.e. pressure leaching or oxidation) can promote the formation of a thermodynamic stable solid ferric arsenate compound called scorodite ($\text{FeAsO}_4 \cdot 2\text{H}_2\text{O}$) and leach copper in a single stage autoclave process (Gomez *et al.*, 2011, p.1; Riveros *et al.*, p.408; Ferron and Wang, 2003, p.2).

Teck’s proprietary pressure hydrometallurgical technology developed by its CESL Limited group (CESL) has the potential to unlock metallurgically challenged resources such as many of the next generation of Greenfield copper projects in Peru bearing high arsenic minerals. Known as the CESL process, the technology has proven that it can achieve excellent metal recoveries from copper concentrates high in enargite while converting virtually all of the arsenic to crystalline scorodite in the leach residue (Mayhew *et al.*, 2010, p.1996). Crystalline scorodite is

considered the most thermodynamically stable form of arsenic for waste disposal practice (Ferron and Wang, 2003, p.2). Based on this, CESL technology represents a potential game changer in the world of high-arsenic copper concentrate refining (compared to traditional smelting), while providing Teck with a competitive advantage in the competition and development of ‘non-traditional’ copper resources.

This brings us to the aim of this paper, assessing the viability of an integrated mine, mill, and hydrometallurgical refinery operation for a hypothetical high arsenic bearing copper-gold deposit located in Northern Peru. This deposit will share similar characteristics to moderate grade Andean style copper-gold porphyry systems located in the region of Northern Peru, and will yield arsenic levels in future concentrate production that is greater than current smelter rejection limits of more than 0.5% arsenic (Haque *et al.*, 2010, p.3217). Annual copper production at the mine site will approach 150 thousand tonnes of copper contained in concentrate with appreciable by-product credits of gold, silver, and a separate molybdenum concentrate. The CESL hydrometallurgical refinery will process the concentrate through to LME grade-A cathode and gold and silver doré metal. Throughout this project the integrated operation will be referred to as “Project Copper-Arsenic (Project Cu-As)”.

With an increasing amount of arsenic contained in current and future copper projects, a sustainable approach to dealing with this hazardous element from exploration, mine development, production processes and eventual mine closure is critical (Ferron and Wang, 2003). Project Cu-As represents a mine to metal concept, which effectively converts high arsenic copper ores to copper metal. Such an operation represents a long-term strategic investment opportunity for Teck’s copper business unit. By successfully commercializing its CESL hydrometallurgical technology in an environmentally and socially sensitive, resource rich copper district such as Northern Peru, Teck would capture a ‘first mover’ advantage (Marsden, 2004, p.14) ahead of their many competitors who are all vying to grow the reserve positions in this region.

As part of this project, a market and industry analysis was completed to support the business case for Project Cu-As and provide the fundamental background, information, and key assumptions required for in the assessment. The objective of the assessment process is to equally consider the economic, social, and environmental values added (or subtracted) by the operation utilizing a commonly referred to Triple Bottom Line (TBL) concept (Esvelt and Karamysheva, 2006, p.2). In doing so, key financial, social, and environmental indicators related to the defined scope of the operation are developed and discussed. Information sourced through above-mentioned market and industry analysis is utilized for the broad TBL assessment. The final

section of the project offers concluding remarks regarding the merits and viability of Project Cu-As. Recommendations pertaining to the successful advancement of Project Cu-As are developed.

2: Background

The following chapter provides important background information with respect to the project at hand. Section 2.1 describes the wealth of copper resource development opportunities in Peru and the central challenge, widespread arsenic sulphide minerals, which has impeded the development of many of these projects through the conventional mine-concentrator to market route. Section 2.2 summarizes Teck's strategic advantage with respect to unlocking high arsenic-bearing copper deposits through the commercialization of its proprietary hydrometallurgical CESL technology. Section 2.3 details how the development of metallurgically challenged deposits (i.e. non-traditional ore bodies) aligns strategically with Teck's continual need as a mining company to grow the reserve base of its copper business unit.

2.1 Peru Copper Opportunity

The Andean district of South America has emerged as the world's leading producing copper region. According to Brook Hunt (a Wood McKenzie company), approximately 45% of global copper mine supply originates from Latin America (i.e. Brazil, Chile, Mexico, Peru, others) (Brook Hunt Copper Long-term Outlook, 2010, p.2). Clearly a rich source of copper mineral resources, the Andes Mountains of South America have significant potential for new projects and will remain a key source of primary copper supply for many years to come. A significant portion of this new mine supply will inevitably be sourced from the country of Peru as it boasts one of the world's largest portfolios of Greenfield copper projects and is the world's second largest copper producer behind Chile (Andina 2010; CRU International May2009, p.2).

Today the search for copper is the lead attraction in Peru as several senior, mid-tier and junior mining and exploration companies are actively pursuing projects (Vaccaro, 2010, p.12). Peru now ranks third behind Canada and Australia in terms of exploration expenditures on the ground (Vaccaro, 2010, p.12). In 2009 CRU reported through its South America Monthlies, that South America was clearly on the top of the ranking when it came to new copper project developments and Chinese investment potential (CRU International May2009, p.1). Despite Chile leading with the greatest production potential, Peru's significant Greenfield projects were highlighted as the next generation of copper mine projects (CRU International Sept2009, p.1).

Compared to Chile where approximately 40% of potential new production is Greenfield, almost 90% of potential new production is Greenfield in Peru (CRU International May2009, p.2). The extent and location of these projects is depicted in Figure 1 (Figure by author, information sourced from Peru’s Ministry of Energy and Mines website, 2011) which highlights several Greenfield copper projects (i.e. exploration), projects confirmed in feasibility, projects with confirmed investment, and those in an expansion phase.

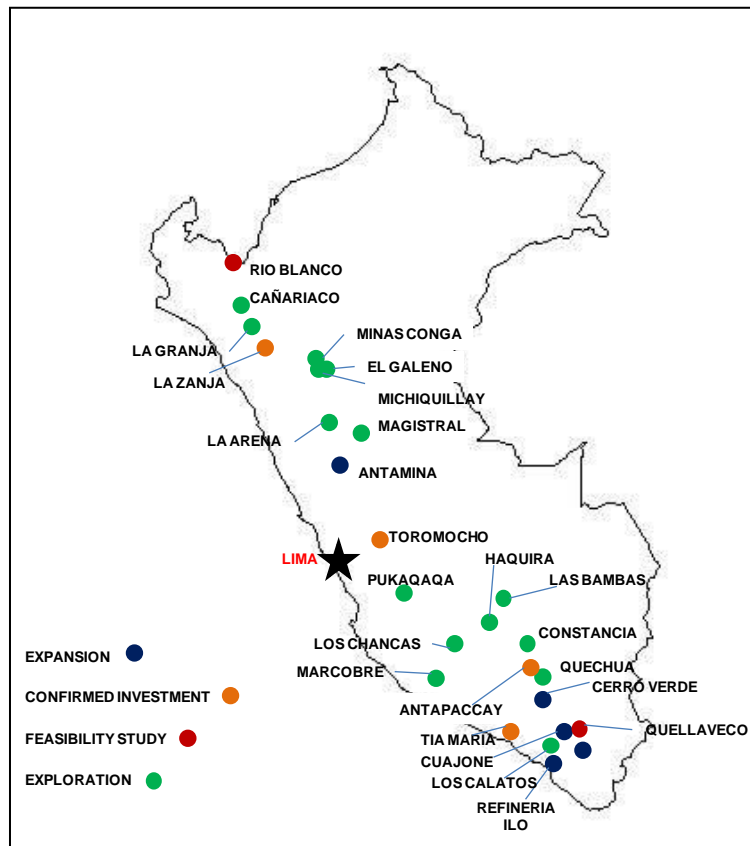


Figure 1: 2011 Copper Projects Map of Peru

Several of Peru’s most significant Greenfield copper projects identified in Figure 1 are profiled in Table 2-1 (Table by author, information sourced from Metals Economic Group 2011, Minsearch data).

Table 2-1: Significant Peruvian Copper Projects

Project	Owner	Investment (US\$ million)	Start Up	Production (kt Cu/yr)
Toromocho	Aluminum Corp of China Ltd	\$2.20B (2009)	2013	250
Galeno	China Minmetals Corp (60%)	\$2.50B (2009)	2012	144
Quellaveco	Anglo American plc	\$3.00B (2010)	2014	225
La Granja	Rio Tinto	\$2.75B (2008)	2014+	300
Michiquillay	Anglo American plc	\$3.00B (2008)	2017	300
Cañariaco Norte	Candente Copper Corp	\$1.56B (2011)	N.D.	100
Rio Blanco	Monterrico Metals plc	\$1.44B (2006)	N.D.	191

The average production from these projects is greater than 200k tonnes per year of contained copper in concentrate. The average capital investment cost is US\$2.35 billion dollars which equates to a unit capital cost intensity for the mine of US\$10890/t of Cu.

2.1.1 Arsenic Bearing Deposits

Despite the attractive portfolio of Greenfield copper projects presented in Table 2-1, one must bear in mind the challenges of developing a new copper mine. In the case of copper concentrate production from ore there are several deleterious elements such as arsenic that can impact marketability and ultimately contribute to environmental and health concerns during concentrate pyrometallurgical processing and disposal of tailings and waste residue materials (Orihuela, 2010, p.5; Nakazawa *et al.*, 1999, p.393). As has been highlighted in various news releases, research, consulting, and corporate technical reports, several of the projects in Peru are technically challenged with lower grades, and also with ore high in arsenic content (e.g. Galeno, Cañariaco Norte, La Granja, and Toromocho), often enargite (Cu_3AsS_4) and tennantite ($\text{Cu}_{12}\text{As}_4\text{S}_{13}$) (Nicolson, 2003, p. 9-6; Thomas, 2010, p.1-8; Metals Economic Group, 2011, p.5; Wood Mackenzie Metal Cost Service, 2010, Toromocho Project). The traditional mine-concentrator-smelter processing route does not appear to be a feasible option, due to the impacts of high arsenic levels on concentrate marketability and processing difficulties at smelter complexes (Dreisinger, 2005, p.3; Baxter and Scriba, 2010, p. 1783/4). Depending on the severity of arsenic content within the resource, a mining company may be able to avoid arsenic by applying selective mining involving such techniques as in-pit blending to manage arsenic, but this will increase mining costs. If arsenic is widespread through the resource, mining companies must consider alternative processing routes or delay the development of the project. Some of the technology options to consider include hydrometallurgical processing, concentrate roasting, and

differential flotation (Baxter and Scriba, 2010, p. 1783/4; Bruckard *et al.*, 2010, p. 1167). These options are profiled later in section 4.2.1.

2.2 Competitive Advantage

New mining and processing technologies have played a critical role in the progressive advancement of the copper industry and can serve as a competitive advantage if effectively implemented with respect to time and scale (Marsden, 2004, p.13). Some well-known historical examples include the widespread adoption of large-scale open pit mining and bulk flotation in the early 1900s, the development of Outokumpu's energy efficient flash-smelting technology in the 1940s, and the commercialization of copper solvent extraction and electrowinning in the late 60s (Marsden, 2004, p.15). As conventional copper deposits become progressively depleted, producers will search for new technologies to economically process deeper, lower-grade, and more metallurgically complex ore bodies bearing higher levels of deleterious elements. The development and eventual commercialization of new technology can be costly and involve risks (Marsden, 2004, p.13). However, thorough testing of new technologies from bench, through to pilot and eventual large industrial demonstration or prototype scales can mitigate excessive development costs and commercialization risk (Barr *et al.*, 2004, p.2-3). This effort will no doubt require sound management practices and a strong technical team. Presented with the right market opportunity which requires new technology, an organization can achieve a competitive advantage given they can effectively implement a proven innovative technological response in a timely and sufficiently scaled manner (Marsden, 2004, p.13).

Today the copper industry faces a growing challenge with respect to the inability of leading conventional smelting technology to accept high arsenic bearing copper concentrates (>0.5%As) and economically treat significant quantities of arsenical containing residues in an environmentally acceptable manner (Baxter and Scriba., 2010, p. 1783; Mayhew *et al.*, 2010, p.1983; Kojo and Storch, 2006, p.236). Not only is the content of arsenic in concentrate expected to rise in future copper projects, but it has also been well reported that arsenic levels are increasing in current commercial copper concentrates (Mayhew *et al.*, 2010, p.1984). This will likely motivate mining and refining companies to consider alternative technologies and processing options such as hydrometallurgy (i.e. concentrate leaching) to treat high copper concentrates bearing high impurities such as arsenic (Brook Hunt Global Copper Concentrate and Blister/Anode Markets, 2010, p.129).

2.2.1 CESL Technology

Innovation has been a key driver of activities at Teck Resources Limited ('Teck') including Exploration, Corporate Development, Project Development, Engineering, and Environment and Sustainability. The Technology Division seeks to identify, develop or acquire the best technology and technically skilled resources in geosciences, mining, mineral processing, energy efficiency, water management and sustainable development to create value and better manage risks at all stages of project identification, development and management.

Teck has developed hydrometallurgical technology known as the CESL Process as an economic alternative to conventional smelting and electro-refining (Barr *et al.*, 2005, p.2). The CESL Process involves the oxidation of sulphide concentrates in an autoclave at moderate elevated pressure (200 psig) and temperature (150 °C) in the presence of catalytic chloride ions (CESL Limited 2011; Barr *et al.*, 2005, p.3). When processing copper concentrates, the oxidized copper minerals (e.g. chalcopyrite) readily leach into solution and are recovered by conventional solvent extraction and electrowinning (CESL Limited, 2011; Barr *et al.*, 2005, p.3). Copper recovery is typically 95-98%, comparable to a smelter (CESL Limited 2010; Barr *et al.*, 2007, p.3). Figure 2 shows the basic copper flowsheet for the CESL Process (Figure by author, modified from flowsheet presented by Barr *et al.*, 2007, p.3). If significant levels of precious metals (i.e. gold and silver) are present in the concentrate, the washed residue from the copper process is treated for precious metals recovery using the CESL Gold Process (CESL Limited 2011; Barr *et al.*, 2007, p.3). The CESL Gold Process is a cyanide-based process characterized by low reagent consumption and competitive metal recovery (CESL Limited 2011; Barr *et al.*, 2007, p.1). The cyanidation step of the CESL Process is done under pressure, which increases the extraction rate of gold and silver. Once the leach is completed, the slurry is filtered and washed. Conventional methods are used to recover the gold and silver to doré metal. The gold and silver is recovered from solution using a standard carbon circuit. Copper is precipitated from a portion of the barren solution. The majority of the solution is recycled directly back to cyanidation. A small bleed stream is treated through cyanide recovery and destruction circuits before being discharged from the process. Figure 3 shows the basic gold recovery flowsheet for the CESL Process (Figure by author, modified from flowsheet presented by Barr *et al.*, 2007, p.3).

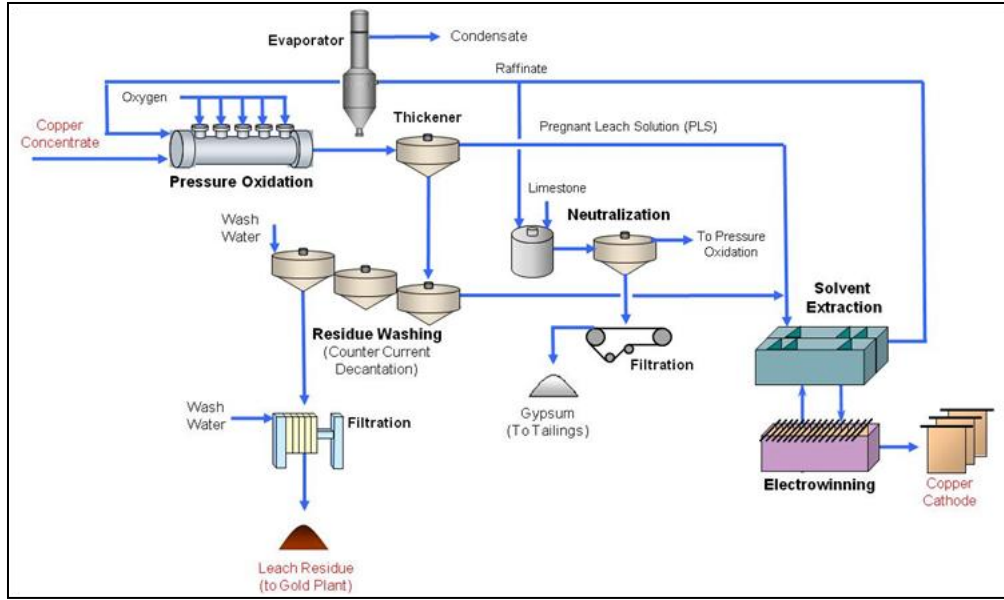


Figure 2: Simplified CESL Copper Flowsheet

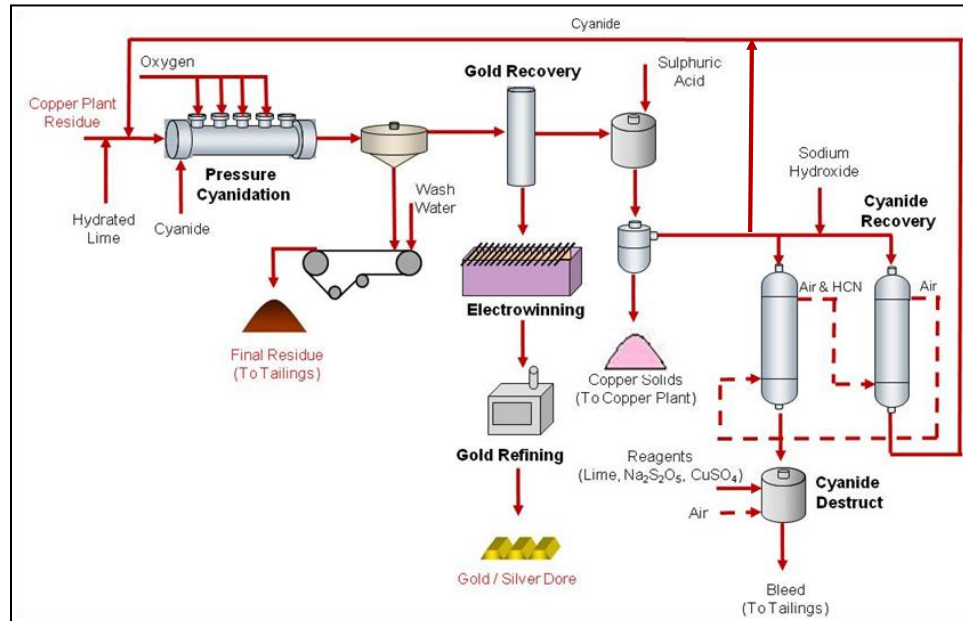


Figure 3: Simplified CESL Gold Flowsheet

Teck's CESL Copper Process has been thoroughly developed and tested at the bench, pilot and demonstration scales (Barr *et al.*, 2004, p.2). It uses proven technologies such as pressure oxidation, solvent extraction and electrowinning but combines them in a novel way (CESL Limited, 2011). The closed-loop process produces no liquid effluents or sulphur dioxide and the only solids produced are gypsum and a leach residue comprised largely of hematite, elemental sulphur and gangue material, which in most cases can be disposed of with associated mill tailings (CESL Limited 2011; Barr *et al.*, 2005, p.4). Supported by a major international mining company, the first commercial-scale CESL hydrometallurgical facility was built by Vale S.A. in the Carajás region of Brazil (Brace *et al.*, 2008; Cabral and Defreyne, 2009; Caufield, 2010, p.20). It had a design capacity of 10,000 tonne per year copper metal and began operations in 2008 before shutting down in the summer of 2010 (Caufield, 2010, p.20). The main purpose of the plant was to serve as a prototype to train personnel in the region and demonstrate the effectiveness of the technology, in order to provide support for the construction of a much larger plant to process nearby concentrates from future Vale projects (Caufield, 2010, p.21; Teck Resources Limited, 2009, Sustainability Report p.52).

Besides successfully treating standard marketable copper concentrates, CESL technology has demonstrated capability to refine "dirty" concentrates containing deleterious impurity elements that pose serious challenges in conventional smelting (CESL Limited, 2011; Barr *et al.*, 2005, p.11). Bench development work in 2009 confirmed the application of CESL technology to high enargite bearing copper concentrates (Mayhew *et al.*, 2010, p.1996). These results confirmed that high copper extraction (97%) with moderate oxidation of sulphur sulphate, an important cost driver in hydrometallurgical processing of sulphide concentrates, could be achieved (Mayhew *et al.*, p.1996). More importantly, majority of the arsenic (~99%) precipitated in the autoclave, a critical aspect of an integrated approach to controlling arsenic. X-ray diffraction (XRD) analysis confirmed the presence of scorodite (crystalline ferric arsenate) with no other ferric arsenate phases being identified (Mayhew *et al.*, p.1996). Crystalline scorodite ($\text{FeAsO}_4 \cdot 2\text{H}_2\text{O}$), along with Type II ferric arsenate ($\text{Fe}_4(\text{AsO}_4)_3 \cdot (\text{OH})_x(\text{SO}_4)_y$), and amorphous arsenic ferrihydrite exhibit acceptable stability in US-EPA TCLP testing for determining safe disposal to tailings ponds (Baxter and Scriba, p.1785; Ferron and Wang, 2003, p.2).

A comprehensive pilot plant campaign in 2010 using high enargite bearing copper-gold concentrates validated the preliminary findings of the 2009 bench testwork results. The pilot plant also served to further define the flowsheet and generate representative residues for subsequent gold recovery and long-term residue stability testwork (Mayhew *et al.*, p.1996). Based on past

academic studies with respect to arsenic stability from medium temperature pressure leaching (Gomez *et al.*, 2011, p.7) and historical precious metal leaching results from the CESL gold process (Barr *et al.*, 2007, p.3) these items are not expected to pose significant future challenges.

2.3 Strategic Alignment

Copper is a core business unit of Teck Resources Limited, known as ‘Teck Copper’. In 2009, Teck Copper had the capacity to produce over 300 thousand tonnes of copper primarily from major mines including Quebrada Blanca and Carmen de Andacollo in Chile, the Antamina mine in Peru and Highland Valley Copper in Canada (Teck Resources Limited, 2010, 2009 Investor Fact Book p.7). Today, Teck Copper is on track to grow its copper business 40% from brownfield projects to 400kt per year by 2013 (Figure 4 by Teck Resources Limited, from BMO Global Metals and Mining Conference March, 2011). As well, Teck Copper has two advancing projects (Quebrada Blanca Hypogene and Relincho) in Chile that have the potential to add an additional 350kt per year (Teck, 2011, BMO Global Metals and Mining Conference March, 2011).

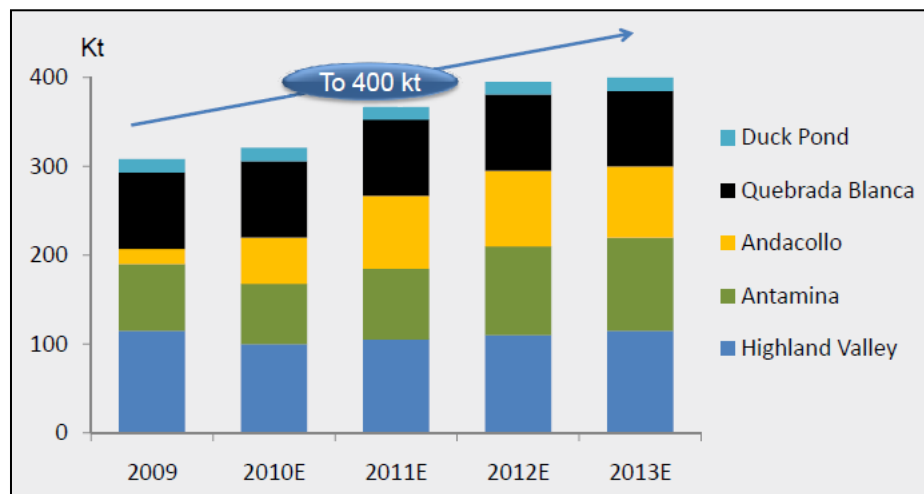


Figure 4: Teck's Copper Growth Profile by 2013

In addition to Teck's impressive copper production growth profile, they are actively exploring and assessing development opportunities for new copper deposits in Canada, Peru and Chile, where they have existing operations, as well as Mexico, the United States, Namibia, Turkey

and Australia. (Teck Resource Limited, 2011, Exploration). The mandate for Teck’s Exploration team is to focus on high quality, sustainable growth opportunities through the discovery or acquisition of top-tier mineral deposits (Teck Resource Limited, 2011, Exploration). What defines a ‘top-tier’ mineral deposit is likely to evolve, as the significance and role of challenged mineral resources such as those high in arsenic are likely to increase in time with the growth in global copper demand. Knowing this, the importance of Teck’s technological advancements such as the CESL copper process, and a strong commitment to sustainability will be critical in future project developments.

2.3.1 Project Development

Mining is Teck’s core business and it requires long-term planning as the company must constantly manage depleting reserves. As a result, Teck must compete aggressively on a global scale for new resources and successfully convert them into reserves, which is the foundation of any mining company. This requires Teck to think strategically when it comes to making long-term investment decisions. Teck Business Development has had several expressions of interest from various mining, exploration, and refining companies over the years with respect to the development of high arsenic bearing resources and processing copper concentrates produced from such projects using its proprietary CESL technology. Teck does not own a copper project with development challenges related to significant and widespread arsenic mineralization. However, the capabilities of its CESL technology provides them with a strategic opportunity to potentially acquire and develop one with sizable contained metal value and or establish a joint venture partnership on a project. Historically the latter fits well strategically as Teck has successfully built its company on a foundation of several joint ventures and partnerships (Keevil, 2006). Teck prides itself on being a “partner of choice®” in the industry on all of its mining ventures (Teck Resources Limited, 2011, Exploration Brochure).

Clearly, the copper growth potential in Peru is an attractive one and Teck has demonstrated throughout its long history that it has the exploration, mining, refining, environmental, and community relations expertise that together could unlock the potential in large arsenic challenged copper resource opportunities. Teck’s experience working in Peru is demonstrated through its 22.5% partnership in Antamina, one of the largest Peruvian producers of copper and zinc concentrates and one of the ten largest mines in the world. Developing new mines in Peru that can clearly benefit from processing using CESL technology is a long-term strategic opportunity for Teck. In doing so Teck can combine traditional mine-concentrate

expertise with established CESL hydrometallurgical processing and copper metal production know-how to develop a “world class” integrated mine-refinery producing LME Grade A copper cathode. However, prior to any project development activity related to advancing opportunities involving technologically challenged high arsenic bearing copper deposits, a project assessment should be undertaken that considers the financial, environmental, and social value added (or subtracted). These core values are central to the sustainable development of extractive industry projects such as those related to copper production.

In the proceeding section, triple bottom line (‘TBL’) thinking is introduced as an effective assessment tool to evaluate the viability of projects. Later in Chapter 5, this methodology is applied directly to Project Cu-As.

3: Project Definition

The following chapter aims to define the project at hand. It begins with an overview of a hypothetical case study in section 3.1 that will serve as the basis for the triple bottom line ('TBL') assessment later in Chapter 5. Further details involving the scope of the operation are outlined in section 3.1.1. Section 3.2 introduces the central challenge facing mining companies today, integrating sustainability into project developments. This is followed by a description of the TBL methodology in section 3.2.1 that will be applied in assessing the viability of Project Cu-As.

3.1 Case Study

The purpose of this section is to describe the boundaries for a hypothetical high arsenic bearing copper-gold project in Northern Peru for evaluation using the TBL framework outlined in section 3.2.1. The implied arsenic level in the copper-gold resource is expected to yield a concentrate that will significantly exceed smelter rejection limits of 0.5%As, averaging ~1.5%As throughout the life of the project. This ultimately precludes the mine from development using the traditional mine-concentrate route, requiring an alternative refining option to smelting. Teck does not currently own a large copper project with development challenges related to significant and widespread arsenic mineralization (i.e., enargite). However, as noted in previous sections, Peru offers a wealth of copper development opportunities, several of which have been precluded or delayed from traditional development options (i.e. mine to market: selling concentrate to smelters) due to high levels of arsenic. Assessing the sustainable development route for a high arsenic bearing copper-gold resource is the basis of this project. Given the best available technology, environmental and mine development plan, and community engagement strategy, these projects can be successfully developed and the metal value in the ground can be unlocked.

3.1.1 Operational Scope

The operational scope of the opportunity that will be assessed using the TBL framework involves a fully integrated mine-mill and hydrometallurgical refinery. This operation is representative of a 'mine to metal concept' (as shown in Figure 5 by author, Scope of Project Copper-Arsenic) involving the whole copper production process from reserves and resource

development (i.e. exploration), to mining the ore through to concentrate production, followed by on-site production of copper metal with leach residue and tailings disposal

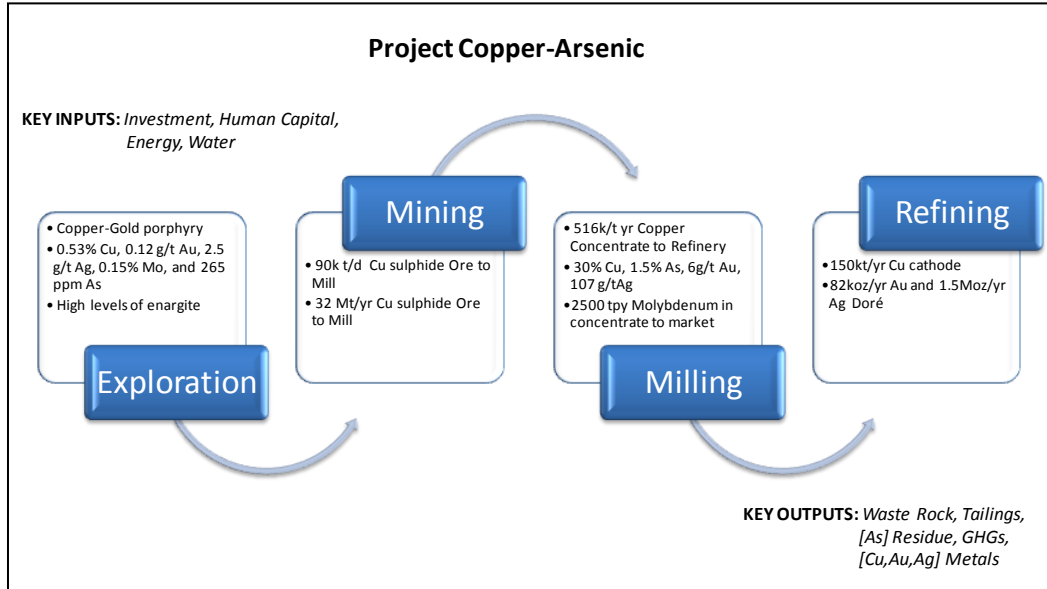


Figure 5: Scope of Project Copper-Arsenic: Mine to Metal Operation

The resource for Project Cu-As is characteristic of an Andean-style mid-grade Cu-Mo-Au-(Ag) porphyry. The grades are typical of several deposits in the Cajamarca and Lambayeque regions of Northern Peru. Ore production is expected to be 90,000 tonnes per day with life of mine head grade averaging 0.53% Cu, 0.12g/t Au, 2.5 g/t Ag, 0.01% Mo, and 250 ppm As. Mining operations will consist of conventional open-pit design with a very low stripping ratio of 0.5 to 1. Ore will be delivered from the mine by haul trucks to crushing and milling where conventional bulk Cu/Mo cleaner flotation is applied. Tailings are thickened before disposal in a tailings impoundment. Molybdenum concentrate is thickened, filtered and dried for shipment in bags. Copper concentrate is thickened and pressure filtered prior to delivery by trucks to the nearby CESL hydrometallurgical refinery. The refinery will be located near the mine in close proximity to the concentrator, mitigating the need for excessive truck, rail, and/or ocean ship concentrate freight to the refinery. Only copper cathode and precious metal doré will be transported from site to overseas markets or future semi-fabrication and casting operations within Peru.

Teck's CESL hydrometallurgical technology is selected to treat the arsenic bearing copper concentrate and produce copper metal along with gold and silver by-products. Competing commercial process technology alternatives are available and justification for selecting CESL technology is provided in section 4.2.2. Table 3-1 summarizes the general production data for the integrated operation. These values will serve as the foundation of the financial portion of the TBL assessment. Other major project assumptions required for the financial model are developed and extracted from the market and industry analysis discussed later in Chapter 4.

Table 3-1: General Production for Mine-Mill-Refinery of Project Cu-As

General Production	
Mining method	Open Pit
Ore Processing	32M mt/y
Strip Ratio	0.5:1
Processing Method	Flotation / Pressure Leaching / Cu SX/EW / Au/Ag Cyanidation
Concentrate Production	~500,000 mt/y
Copper	~150,000 mt/y Cu as cathode
Gold	~82,000 oz/y Au (Dore)
Silver	~1.5M oz/y Ag (Dore)
Molybdenum	~2500 mt/y Mo in concentrate

The regional location of the operation is targeted for Northern Peru. Much of the electricity in Peru is supplied by hydroelectric power (Tejerina *et al.*, 2010; CRU International, 2008, p.13). However electrical power generation by natural gas (NG) has grown by 54% between 2004 and 2008 to 33% (Tejerina *et al.*, 2010). For Project Cu-As the mine site energy supply was assumed to be one third from diesel and two thirds from electricity (produced by NG at 80% efficiency). The copper mine unit energy requirements for Project Cu-As were factored from a copper mine industry average of ~23.1 GJ/t C (Farrel, 2009, p.29). Based on the above fuel type assumptions Project Cu-As would have a total mine site unit energy requirement ~26.9 GJ/t Cu. The resulting unit carbon dioxide mine site emissions were calculated to be ~1.53 t CO₂(e)/t Cu. The electrical energy requirements for the refinery will also be fuelled by natural gas based on its recent supply growth in Peru (Tejerina *et al.*, 2010; CRU International, 2008, p.13). Using past CESL feasibility level study data the unit energy requirements for the refinery were estimated to be ~17.4 GJ/t (CESL Limited, 2007). On that basis the unit carbon dioxide emissions were calculated to be ~0.87 t CO₂(e)/t Cu. After factoring for gypsum production (i.e. CO₂ from acid neutralization by limestone) the resulting unit carbon dioxide refinery emissions rose to ~1.33 t CO₂(e)/t Cu. The total mine-mill-refinery unit energy and carbon dioxide emissions were

~44.3 GJ/t and ~2.9 t CO₂(e)/t Cu respectively. The above values were calculated using high heat value and emission rates by fuel type extracted from the British Columbia Reporting Regulation Methodology Manual (British Columbia Reporting Regulation Methodology Manual, 2009) and carbon dioxide equivalent factors for nitrous oxide and methane from the Intergovernmental Panel on Climate Change (sourced internally from Teck). Colin Miller (Senior Project Leader, CESL Process Engineering Department) advised on the unit energy and carbon dioxide emission calculations for Project Cu-As.

Water consumption is an essential input to mining projects and is highly variable based on a number of project specific factors including metal ore grades (Mudd, 2008, p.137/8). Estimated water requirements for the mine site at Project Cu-As were based on an industry average water usage for copper miners of 172 m³/t Cu (Mudd, 2008, p.142). The water requirements for the CESL refinery were factored from past CESL feasibility level study data and are substantially less at ~3.6 m³/t of Cu (CESL Limited, 2007). In total, the fresh water requirements for Project Cu-As are estimated to be ~176 m³/t of Cu.

The total waste rock and tailings generated from the mine site far outweighs the volume of leach residue produced from the hydrometallurgical refinery. The hematite and elemental sulphur rich leach residue (i.e. high in arsenic as scorodite) and acid neutralized residue (i.e. gypsum) generated from the CESL refinery would be less than ~1% of the total mine waste rock and tailings produced from Project Cu-As. The low strip ratio (ore to waste) of 0.5 to 1 for Project Cu-As results in a mining waste rock to copper produced value of ~332 kg/kg Cu. The total mass of dry tailings produced is estimated to be 32 million tonnes per year or ~215 kg/kg Cu.

Further key financial (e.g. mine-mill-refinery capex and opex), environmental and social considerations specific to Project Cu-As and the region of Peru are developed and extracted from the market and industry analysis presented in Chapter 4. These key findings are later incorporated later into the TBL assessment for Project Cu-As in Chapter 5.

3.2 Integrating Sustainability

The technical challenge that mining companies will face with the metallurgic complexity of future ore deposits is only part of the story when it comes to developing new copper mining projects. Today mining companies require significant advance planning when it comes to the wide range of economic, social, and environmental issues that are central to the development of projects while preserving their ‘social license to operate’ (Deloitte, 2011, p.5; Esvelt and Karamysheva, 2006, p.6; Nelsen and Scoble, 2006, p.2). This is a significant challenge and

requires the integration of sustainable development into strategic project decisions (Deloitte, 2011, p.5; AMIRA International, 2004, p.8). Although this concept of sustainable development is well known and accepted in the mining and exploration industry, it has proven to be very difficult for companies to manage and apply successfully (Lenzen at al., 2006, p.3; Deloitte, 2011, p.5). Sustainable development can be viewed as a holistic process that integrates financial, environmental and social considerations on an equal weighting (Lenzen at al., 2006, p.3). Ultimately the process requires that mining companies engage with key stakeholders early at all stages of project development, operation, and eventual mine closure (Deloitte, 2011, p.5; Stratos Inc. 2008, p.5-6). For a new project to successfully journey towards sustainable development, it must contribute economic value to the company (i.e. Teck), its employees, the surrounding community, suppliers and stakeholders affected by the development. Secondly, the project must avoid causing irreversible harm to ecosystems and biodiversity and when possible contribute environmental value. Lastly, the project must contribute social value, improving the lifestyles of the people affected by the project's activities.

When it comes to the development of non-traditional resources, it is critical that industry demonstrates new mining and processes technologies that maintain the above values for sustainable development, providing long-term economic and social benefits while maintaining strong environmental and health performance measures with respect to worker safety, waste disposal, biodiversity, and land and water usage (AMIRA International, 2004, p.7-8). One way to assess whether a project could effectively deliver on these measures is to apply John Elkington's triple bottom line (TBL) thinking, ultimately created to assess and report on the three spheres of sustainability: economic, social and environmental (Lenzen at al., 2006, p.3). A TBL assessment can serve as an effective tool to assess potential projects and identify gaps and areas needing improvement. In doing so, a clear path towards sustainable development can be seen and a mining company can ensure it maintains its social license to operate.

3.2.1 Triple Bottom Line

Economic success ultimately depends on a sound environment and healthy communities. The traditional discounted cash flow analysis commonly used to evaluate projects has a very limited ability to consider the broader environmental and social issues, which are central to evaluating possible projects and establishing a sustainable operational plan (AMIRA International, 2004, p.14; Evans *et. al*, 2006, p. 97). Nonetheless, this has been the basis for project evaluation and in many cases; it still is a heavily weighted component. One of the main

challenges stems from the inability to establish meaningful metrics for the social and environmental indicators within projects (AMIRA International, 2004, p.14). Past surveys conducted in the minerals sector (i.e. Mining, Minerals, and Sustainable Development Project, MMSD) revealed that many companies had indicated a lack of a clear business case as part of the problem in implementing sustainable development goals (Walker and Howard, 2002, p.13). Interestingly, the same companies who participated in the survey cited shareholder value as the primary reason for pursuing sustainability (Walker and Howard, 2002, p.13). Knowing this it is essential to identify clear measurable metrics to quantify not only the economic, but the social and environmental aspects of a project going forward.

A commonly known methodology called the triple bottom line ('TBL') model can be relatively effective when evaluating the core economic, social, and environmental values of a project that were mentioned earlier (Esvelt and Karamysheva, 2006, p.2; AMIRA International, 2004, p.14). Developing a TBL scorecard method for quantifying and assessing the impacts of each value component (both positive and negative), can provide project developers with a more complete ('holistic') approach to evaluating potential mining projects. (AMIRA International, 2004, p.14) More importantly, mining companies that can effectively integrate and balance the economic, environmental and social TBL values into their corporate sustainability strategy, while anticipating any challenges, will likely acquire a competitive advantage, strengthen their overall market position, and establish long-term sustainability (Esvelt and Karamysheva, 2006, p.3).

It is the focus of this project to develop a series of key indicators associated with the development of a strategic integrated mine-mill, and hydrometallurgical-refinery for a large high arsenic bearing, copper-gold deposit in Northern Peru (i.e. Project Cu-As). The TBL indicators will focus on the environmental values and contributions, social and community needs and broader financial benefits of the project. In some cases, key indicators can be associated with all three TBL values. Water is an excellent example as it is a fundamental need to sustain life (Evans *et. al*, 2006, p. 97). For the purpose of this report each of the values were assigned four indicators and there was no overlapping of indicators. The financial indicators are resource quality (RQ), profitability (P), product marketability (PM) and production growth (PG). The social indicators are community impacts (CI), employment generation (EG), health and safety (H&S), and skills development (SD). The environmental indicators are energy and green house gas emissions (E&GHG), land use impacts (LUI), water consumption (WC), and waste generation (WG). Figure 6 captures the key indicators in each of the three aspects that will comprise the case study evaluation (Figure by author).

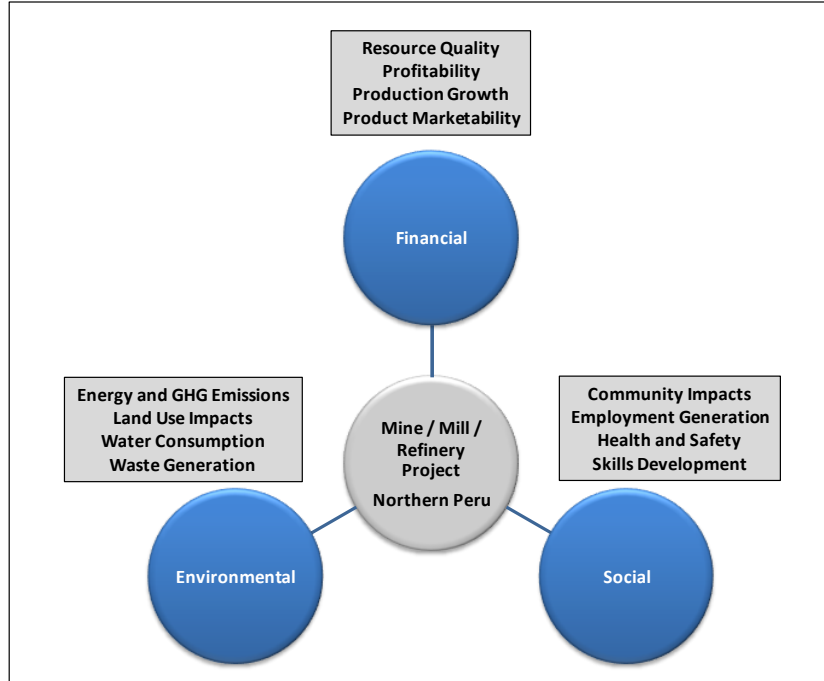


Figure 6: Triple Bottom Line Indicators for Project Assessment

The TBL methodology is employed to provoke thinking around the project’s financial performance and broader social and environmental issues. On a cumulative basis, summing the positive and negative contributions from each of the key indicators can provide insight or guidance on the viability of the project. The TBL framework is not meant to replace the mature and well-established Impact Assessments used by governments in their project approval processes (i.e. Environmental and Social Impact Assessments). Rather, it should be used to initiate focused discussions about key areas needing considerable improvement before a project could be advanced to a tangible development stage. This project will demonstrate the use of a simple and effective TBL method to evaluate a new future copper opportunity for Teck’s Copper Business Unit.

4: Market and Industry Analysis

The objective of Chapter 4 is threefold. First, section 4.1 provides an overview of the long-term outlook for copper and its importance to new project developments for copper. This section lends support for the fundamental need to significantly grow global copper mine supply over the next 10 years. Second, section 4.2 describes the challenge facing the copper industry with respect to arsenic and the rationale for a complete hydrometallurgical solution using Teck's CESL technology integrated with a mine site. Last, section 4.3 examines the key economic, environmental, and social aspects of copper mining and refining in the target market of the case study, Peru. Together, these findings help support the TBL methodology used in Chapter 5 to assess the viability of Project Cu-As.

4.1 Long-Term Outlook for Copper

Decisions around new project developments will always focus around a view of the market, current and future. To determine the likelihood that non-traditional copper resources will soon become highly probable projects for near-term development, a good understanding of the fundamentals for copper supply and demand is required. The following overview on the long-term outlook for copper reviews the current copper supply and demand status (sub-section 4.1.1) and its likely impact on future project developments and commodity pricing (sub-section 4.1.2).

4.1.1 Supply and Demand

Global production (supply) and consumption (demand) of copper has increased significantly in the past quarter century (Doebrich, 2009). Rapid expansion of a middle class in emerging markets (i.e. Asia, Latin America and Eastern Europe) has fuelled an impressive demand for industrial commodities such as copper, which are required for infrastructure development. The consensus key driver behind copper demand has been China's economic development. Over the next five years (2011-2015), copper consumption may increase 25% from 2010 demand forecasts to 8.5 million tons by 2015 (Burns, 2010, November). Strong demand for the red metal is generating significant pressure on industry to find and develop new mine capacity. This is critical as the majority of the world's copper supply comes from primary copper

production (~65%, copper originating from ore) compared to secondary copper production (~35%, copper from recycling) (Risopatron, 2010, p.2216). Despite increased levels of dematerialization and recycling, the voracious demand for copper will continue well into the future as the global population increases and more people achieve a higher standard of living. A common theme among industry leaders has been that demand will continue to outpace supply in the near-term. In a November 2010 article in the Financial Times, chief executive Richard Adkerson of Freeport-MacMoRan Copper and Gold and chief executive Diego Hernández of state-owned Chilean miner Codelco, both stated they expect copper demand to outpace supply for quite some time largely due to ongoing supply challenges (Blas and Farchy, 2010). This was significant considering the two firms combine to produce nearly a quarter of the world's copper (Blas and Farchy, 2010). According to Hernández, a major supply challenge for the industry is the quality of new projects, which are not as good as currently producing mines (Blas and Farchy, 2010). Adkerson noted that supply challenges can be expected as open pit mines are getting larger and more mature (Blas and Farchy, 2010).

Although it is important to recognize and appreciate the status of the copper market today, it is necessary to take a long-term view to appreciate the scope of supply challenges facing the industry. An analysis by Teck (Figure 7 by Teck Resources Limited, from BMO Global Metals and Mining Conference March, 2011) demonstrated that when considering current production, future expansions / closures, highly probable projects and factoring in a conservative demand growth rate of 3% per annum, an additional 6.6 million tonnes of copper per year would be required by 2020. This equates to 45 new copper projects at an average annual production rate of 150 thousand tonnes (Teck Resources Limited, 2011, BMO Global Metals and Mining Conference March, 2011). This magnitude of demand is supported by leading metals research and consulting firm Brook Hunt (a Wood MacKenzie Company) who also believe strong copper demand will continue pressure the supply side (Coombs, 2010, p.2112). In a paper presented in June 2010, David Coombs of Brook Hunt indicated that 8 million tonnes per annum (Mt/a) of additional mine capacity will be required over the next decade (Coombs, 2010, p.2112). A significant portion of this new capacity will come from Greenfield projects (~55%) which is rather challenging considering the geographical distribution of available resources for exploitation (Coombs, 2010, p.2112). This will be a challenge going forward, considering the time and costs involved in developing new copper mines and the fact that there are about ~30 existing mines with annual copper production rates at this level or higher (Teck Resources Limited, 2011, BMO Global Metals and Mining Conference March, 2011).

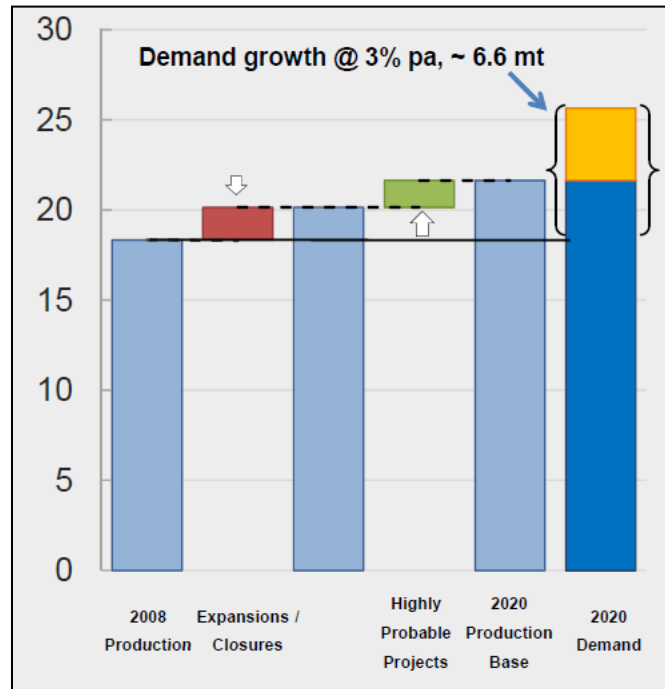


Figure 7: Copper Demand Outpacing Supply (Teck 2011)

The heightened demand for new mine capacity described above will ultimately force miners to consider the development of non-traditional copper resources such as those high in arsenic bearing minerals in order to meet demand. This is evident in the market place today with several projects in Peru bearing high levels of arsenic moving from grassroots exploration through to pre-feasibility, feasibility, and near-term construction and eventual production. What remains unclear is how widespread the arsenic content is for many of these projects. Some miners will be forced to consider alternative refining options for their concentrate and will struggle to produce a marketable concentrate low in arsenic content (<0.5%As), while others will manage through selective mining and in-pit blending to produce concentrate for sale. The later will inevitably increase mine site costs and most likely restrict the full potential of the life of mine.

4.1.2 Copper Price

It is virtually impossible to predict the price of copper five or ten years from now. Many prognosticators provide guidance and offer forecasts on pricing, but they are rarely correct. Regardless, metal prices are a key input when contemplating the development of new projects.

Discussions around supply challenges caused by falling ore grades, metallurgically complex orebodies, lengthy project approval and development times, and strong demand from China, have fuelled a common belief that prices will remain high for quite some time. Although this general trend is possible, it is equally important not to lose track of the impact that significant new production will have when it comes on-line (Burns, 2010, February). High copper prices provide significant incentive to explore for copper, develop new projects, and expand current operations. The inevitable impact of high copper prices will result in increased supply from both primary and secondary sources. Historically, the supply side eventually outpaces demand (Coombs, 2010, p.2104). This relationship will eventually curtail the price of copper, forcing shutdowns and allowing supply to become in balance with demand (Coombs, 2010, p.2104). It is also worth considering the long-term impact of substitution on copper price, and the efforts made to reduce costs by reducing the amount of metal usage through the use of advanced engineering design (Burns, 2010, February).

Leading metals research and consulting firms such as Wood MacKenzie’s Brook Hunt provide guidance on the long-term copper price, factored from their analysis of mine project incentive prices and projected demand for mine production over a given period (Coombs, 2010, p.2104). Many corporations refer to these reports but often utilize internal metal pricing forecasts and scenarios in their project evaluations. For the assessment of Project Cu-As, assumptions around the long-term price of copper, will be extracted from external research sources such as Brook Hunt. Based on their analysis, an incentive price of around \$2.50/lb is reasonable over the period to 2025 (Brook Hunt Copper Long-term Outlook, March 2011, p.2). Price assumptions for by-product credits generated from Project Cu-As such gold, silver, and molybdenum are equally challenging to forecast. Near-term outlooks from consultants for each of these metals were referred to in order to generate an estimate (by author) on a reasonable long-term price (Metals Economic Group, 2010, Bascur, 2010). The copper and by-product metal prices used in the financial assessment of Project Cu-As are displayed in Table 4-1.

Table 4-1: Metal Prices Used in Project Evaluation

Metal	Long-term Price Assumption	Source
Copper	US\$2.50/lb	Brook Hunt, 2010 Copper long-term outlook
Gold	US\$850/oz	Metals Economic Group, 2010 outlook for gold
Silver	US\$18/oz	Metals Economic Group, 2010 outlook for silver
Molybdenum	US\$12/oz	MolyExp, 2010 Molybdenum market outlook

4.2 Copper-Arsenic Challenge

Due to a rather large imbalance between copper concentrate supply and smelter capacity over the last few years, smelter profitability has been negatively affected (Superneau, September 2010, p.2). Some industry experts have referred to this imbalance as excess smelter capacity while others indicate it is a mine supply challenge (Superneau, September 2010, p.2). Either way, the copper concentrate market has definitely favoured the miners because treatment and refining charges (TC/RC), which are a significant component to the market mechanism used to determine the net value of copper concentrates, have been very low by historical standards. (Brook Hunt Global Copper Concentrate and Blister/Anode Markets, 2010, p.31). This trend is certainly not healthy for the smelting and refining industry as it suppresses profits and limits investment in new technology to cope with increasing demands to improve processes to meet tightening environmental performance standards.

One of the most significant technical challenges facing copper smelting processes (e.g., Mitsubishi, Isasmelt, Outokumpo flash and Peirce-Smith converter) is the handling of arsenic in their respective processes (Chen *et al.*, 2010, p.1175). High levels of arsenic in custom copper concentrates are largely driven by gradual depletion of clean high-grade ores with low arsenic levels (Chen *et al.*, 2010, p.1175). Over the last few years, there has been an increase in the level of arsenic in certain commercial concentrates, which has caused growing concern for the world's largest smelter and refining markets including Japan and China (Brook Hunt Global Copper Concentrate and Blister/Anode Markets, 2010, p.195). This general trend can be seen in Figure 8 (Figure modified by author, from Mayhew *et al.*, 2010, presented at Copper 2010 in Hamburg, Germany).

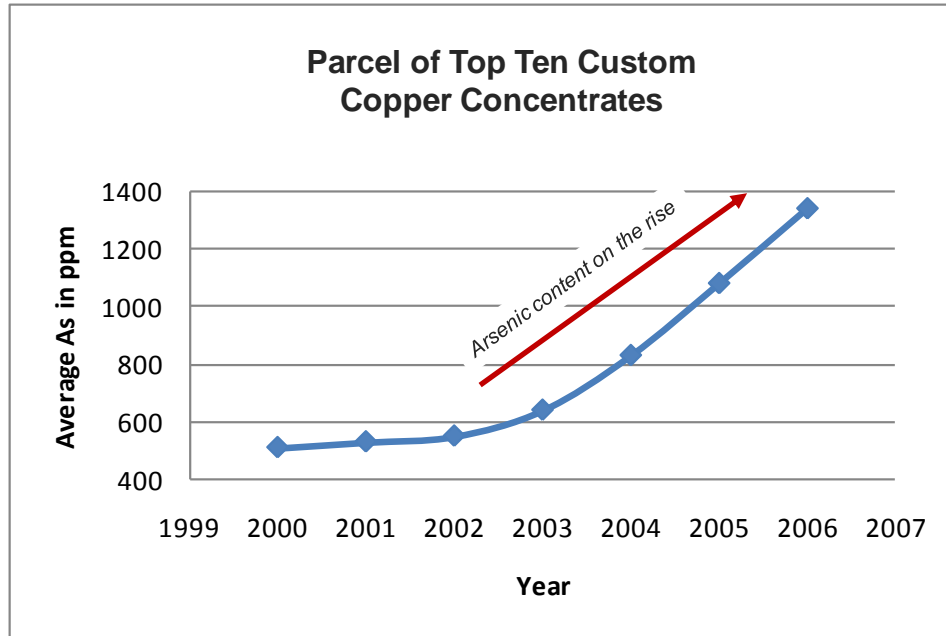


Figure 8: Trend in Average arsenic content in parcel of the top 10 custom concentrates

According to Brook Hunt, copper concentrates bearing varying elevated levels of arsenic are relatively widespread coming from countries such as Bulgaria, Mexico, Namibia, Peru, Philippines and Romania, Albania, Armenia, Australia, Canada, Chile, Kazakhstan, Mongolia, Russia, Turkey and the USA (Brook Hunt Global Copper Concentrate and Blister/Anode Markets, 2010, p.193).

In the smelting process, arsenic in copper concentrates is difficult to handle, reporting to various flue dusts and slag, and disposal of these materials result in a significant cost to smelters (Dreisinger, 2005, p.3; Mayhew *et al.*, 2010, p.1983; Brook Hunt Global Copper Concentrate and Blister/Anode Markets, 2010, p.193). More importantly, the production of compounds such arsenic trioxide (As_2O_3) by some smelters as a means of handling and disposal is no longer an acceptable practice (Riveros, 2001, p.395). Such arsenic wastes pose significant environmental and health risks due to their high water solubility and as a result, smelters are experiencing ever-tightening environmental restrictions on allowable disposal limits (Ayowole, 2008, p.6; Bruckard *et al.*, 2010, p. 1167; Riveros *et al.*, 2001, p.396). In the flash smelting process, arsenic-containing residues collected from the wet gas cleaning section and effluent treatment process has typically been stabilized through precipitation of arsenic as ferric arsenate (Kojo and Storch, 2006, p.236). However, there are uncertainties as to the stability of this amorphous form of

arsenic residue over the long term, forcing smelters to investigate economic means to stabilize arsenic as scorodite, a more thermodynamically crystallize form of ferric arsenate (Kojo and Storch, 2006, p.236). Smelter complexes can no longer afford to stockpile large amounts of unstable and harmful arsenic wastes. This has contributed to lower thresholds for arsenic in commercial concentrates and higher penalty levels with rejection above 0.5%As. In addition to the costs associated with removal and treatment of flue dusts, exposure to arsenic emissions has been a serious problem and challenge to manage in some of the world’s largest copper mining and pyrometallurgical environments (Orihuela, 2010, p.5). There is always the potential exposure to fine dusts bearing arsenic, and in the electrowinning tankhouses there is a risk of lethal arsine gas generated from arsenic in the electrolyte solution. (Brook Hunt Global Copper Concentrate and Blister/Anode Markets, 2010, p.193)

Historically China’s smelters were very flexible in their willingness to process a wide range of concentrates, including those containing significant deleterious elements. However, recent , stricter regulations introduced by Chinese officials, prevent Chinese smelters from importing copper concentrates containing more than 0.5% As (Brook Hunt Global Copper Concentrate and Blister/Anode Markets, 2010, p.196). This leaves the copper industry in a difficult position when faced with the development of large copper resources bearing significant arsenic. Smelters are highly efficient and can most certainly handle the additional copper capacity. Where they will struggle is with their capacities to handle significant arsenic. Based on this it is highly unlikely according to Brook Hunt that smelters will enter into long-term contracts with concentrates bearing substantial tonnages of arsenic (Brook Hunt Global Copper Concentrate and Blister/Anode Markets, 2010, p.195). As well, given the rejection level China has implemented at 0.5%As, the market for concentrates with high arsenic is limited and the penalties scale up considerably from there as shown in Table 4-2 (Table by author, data from Brook Hunt Global Copper Concentrate and Blister/Anode Markets, 2010, p.196). There are only a few smelters in the world that would entertain treating concentrates with such high levels of arsenic (Brook Hunt Global Copper Concentrate and Blister/Anode Markets, 2010, p.193).

Table 4-2: Penalty Limits and Charges for Arsenic in Copper Concentrates

Arsenic Limit	Penalty Range per DMT Over Limit
0.2% As	\$1.50-2.50/DMT per 0.1% up to 0.5%
0.5% As (rejection level)	\$6/DMT per 0.1% between 0.5% and 1%
1.0% As	\$8.50-10.00/DMT per 0.1% above 1%

With the implied demand for new copper mine supply suggested in section 4.1, the rate at which traditional grade copper ore deposits become mined and depleted will no doubt increase. More importantly, high-grade copper resources free from deleterious elements will become scarcer. These facts will inevitably force copper miners to evaluate lower-grade, deeper, and more metallurgically complex ore deposits such as those bearing high levels of arsenic. As a result copper companies will need to explore new technologies and innovative processes to produce copper from arsenic-challenging orebodies.

4.2.1 Process Alternatives Analysis

There are limited options to consider at the mine site when dealing with copper resources bearing high levels of arsenic. Given a sound geological understanding of the reserves and resource, mine planners can determine if in-pit blending to selectively mine around the arsenic is possible. In doing so, miners can avoid high arsenic zones of the orebody and exclude arsenic minerals from the milling and concentrate production stage. If the arsenic is not significant compared with the whole deposit this may be an option. However, the associated operating costs could be high and a decision on how to handle and process the high arsenic ore will need consideration in the future. More importantly, if arsenic is widespread through the orebody, selective mining is not a viable option. In this case, the copper resource would likely be precluded from development using the traditional mine to market concentrate sales to smelters.

On the processing side, there are several options, which have been considered for treatment of high arsenic bearing copper-gold concentrates (Baxter and Scriba, 2010, p. 1786). There are a few technological options designed to remove arsenic from concentrates, which have garnered considerably more market attention than others have. Most notably is one involving concentrate roasting paired with selective (differential) flotation. Differential or selective flotation aims to produce a low-arsenic high-copper concentrate for commercial sale and a high-arsenic low-copper concentrate for subsequent treatment (Bruckard *et al.*, 2010, p. 1167). It has been proposed that the high-arsenic concentrate would be processed through a concentrate roasting plant to selectively remove the arsenic (Bruckard *et al.*, 2010, p. 1168). A low arsenic calcine product is produced from the roaster, which is high copper grade and low in sulphur but can still be smelted directly (Bruckard *et al.*, 2010, p. 1168). The arsenic collected from the roasting process streams then needs to be precipitated (i.e. treated) to produce a thermodynamically stable ferric arsenate product called scorodite (Peacey *et al.*, 2010, p.1040; Baxter and Scriba, 2010, p.1787). The major challenge facing selective (differential) flotation is achieving a successful

split that will yield a low-arsenic high-copper concentrate that is easily marketable. Some of the best results from such flotation applications still yielded arsenic levels above rejection limits (>0.5%As) in the low-arsenic high-copper concentrate from ore head grade of 1200 ppm As (Bruckard *et al.*, 2010, p. 1169). To date selective (differential) flotation flowsheets have been tested at the laboratory scale, but have not yet been commercially approved. However, the roasting portion of the arsenic removal flowsheet is a commercially proven technology and as a stand-alone process, it has been recently proposed for application at high enargite-bearing projects in Chile and Peru. These projects include Codelco's Ministro Alejandro Hales located in Northern Chile (Mining Magazine, 2010) and Candente Copper's Canariaco Norte project located in Northern Peru (Thomas, 2010, p.1-6). Codelco's Ministro Alejandro Hales project has been approved and is progressing towards construction. Candente's project is only in the prefeasibility stage level and it involves a dedicated on-site concentrate roaster requiring that calcine and acid be shipped off-site for further refining and processing. The roasting option should integrate well into Codelco's Chuquicamata mining complex where the arsenic-depleted calcine would feed directly into their existing smelter complex. As well, existing infrastructure is available for handling acid and arsenic waste residues at this large copper mining and smelting site.

There are two distinct concentrate roasting options, reducing using a rotary kiln (RK) and oxidizing using a fluid bed roaster (FBR) (Peacey *et al.*, 2010, p.1042). In the reductive roasting process arsenic is volatilized from the copper concentrate as As_2S_3 gas and eventually oxidize to As_2O_3 with formation of SO_2 which is later recovered as sulphuric acid in a sulphuric acid plant (Baxter and Scriba, 2010, p.1787). Dust from the roaster is cooled to produce a combined arsenic-depleted, sulphur-poor calcine product, which can be sold to smelters (Baxter and Scriba, 2010, p.1787). Copper and precious metal recoveries to the calcine have been reported to be good. (Baxter and Scriba, 2010, p.1794). The As_2O_3 is captured into the solution from the gas cleaning circuit requires further treatment to stabilize the arsenic preferably as crystalline scorodite. There are multiple arsenic treatment options available for the concentrate roasting option. Oxidative atmospheric hydrometallurgical processing has been suggested which requires significant amounts reagents including hydrogen peroxide, ferric sulphate, and limestone (Baxter and Scriba, 2010, p.1787; Ferron and Wang, 2003, p.2) but is likely less costly than using a dedicated high temperature pressure leach with the sole purpose of fixing arsenic as crystalline scorodite (Peacey *et al.*, 2010, p.1041).

In the oxidative roast majority of the calcine is recovered initially in the hot cyclones and some from the FBR bed (Peacey *et al.*, 2010, p.1043). Additional calcine is subsequently

recovered in the off-gas cleaning stages as electrostatic precipitator dust (ESP) (Peacey *et al.*, 2010, p.1043). The ESP dust has considerable metal value and therefore must be blended to the final calcine product (Peacey *et al.*, 2010, p. 1043). However, due to the higher arsenic content of the ESP dust, the arsenic content of the final calcine product will increase (Peacey *et al.*, 2010, p. 1043). In this case, the calcine product from the reductive roast will have a lower arsenic content than the oxidative roast, but the metal recovery will be lower due to losses of fine particles in the arsenic sulphide-sulphur filter cake (Peacey *et al.*, 2010, p. 1043). As previously mentioned, another arsenic precipitation method available to treat the weak acid from the oxidative roaster, is high temperature pressure oxidation, commonly used to treat refractory gold concentrates in the gold industry (Peacey *et al.*, 2010, p. 1043). This option would require a pyrite to supply a source of iron for the production of ferric arsenate as scorodite in the autoclave (Peacey *et al.*, 2010, p. 1043).

Pressure concentrate leaching using an autoclave is a leading option for a complete hydrometallurgical treatment of high-arsenic bearing concentrates. It offers a single stage, once-through process that oxidizes and leaches metals while fixing the arsenic in a stable form (i.e. scorodite). There are two possible routes to consider: a high temperature (HT) and a medium temperature (MT) pressure oxidative leach. The HT pressure leach process requires significant quantities of oxygen due to the total oxidation of sulphides to sulphate (Baxter and Scriba, 2010, p.1788; Mayhew *et al.*, 2010, p. 1995). The weak acid solution that is subsequently generated has to be neutralized with limestone unless a secondary copper mineral resource is nearby, which can be integrated with the leach plant (Baxter and Scriba, 2010, p.1788). This inherently impacts the economics of the process negatively due to the large capital equipment requirements of the HT autoclave vessel and higher consumables for acid neutralization (Mayhew *et al.*, 2010, p.1995). Although it has been commonly applied in the gold industry, HT pressure leaching of enargite-rich concentrates has been well studied, but it has not been commercially applied yet (Ford *et al.*, 2009, p.373; Peacey *et al.*, 2010, p. 1036). It has however been commercially applied on copper concentrates at Sepon (Laos), Kansanshi (Zambia), and Bagdad (Arizona) (Baxter and Scriba, 2010, p.1788). Copper and gold recoveries have been reported to be very high (Baxter and Scriba, 2010, p.1794; Ford *et al.*, 2009, p.376), however there is evidence that in some cases lower copper recovery (~90%) has occurred due to the formation of a Fe-Cu-As-S-O compound formed during the HT pressure leaching of enargite-rich copper concentrates (Mayhew *et al.*, 2010, p.1995). As well, lower silver recoveries due to the formation of argento-jarosite are common. (Peacey *et al.*, 2010, p. 1039). A subsequent lime boil treatment prior to gold cyanization of the autoclave leach residue may raise silver recovery results to higher levels (75-95%) (Peacey *et al.*,

2010, p. 1039). At HT pressure leaching temperatures of 220-230°C, it has been well reported that scorodite is formed (Baxter and Scriba, 2010, p.1794; Peacey *et al.*, 2010, p. 1039) however, there is evidence (i.e. XRD analysis) to suggest that at these temperatures and under chloride conditions, little to no scorodite is formed. (Mayhew *et al.*, 2010, p.1995)

MT pressure leach processing, typically low to medium temperatures up to 160°C, does not fully oxidize sulphides to sulphate. Rather, a significant portion is converted to elemental sulphur hence improving the overall capital and operating cost structure over the HT pressure leach option. Considerable testwork had been undertaken on MT pressure leach technology. As profiled in sub-section 2.2.1 of Chapter 2, Teck's CESL technology has been well tested and proven on a number of copper concentrates in a large-scale demonstration plant (1.5t/d Cu cathode) as well as in a smaller pilot plant (Brace *et al.*, 2008). More recently it was applied in a large prototype plant (10k/tpa Cu cathode) owned and operated by Vale S.A. in the Carajás region of Brazil, to validate the technology on a commercial basis for future projects (Brace *et al.*, 2008; Cabral and Defreyne, 2009; Caufield, 2010, p.21). Vale sourced commercial concentrate from its nearby Sossego mill to feed the CESL copper refinery. Although it has not been commercially applied to high-enargite bearing copper concentrates yet, this concept has been well tested at the bench and continuous copper and gold pilot scale. As was highlighted in sub-section 0 of Chapter 2 (Background) the CESL process achieved high copper extraction (97%) with moderate oxidation of sulphur sulphate. Majority of the arsenic (~99%) from this work precipitated in the autoclave and XRD analysis confirmed the presence of scorodite (crystalline ferric arsenate) with no other ferric arsenate phases identified. Historical gold and silver recoveries from MT pressure leach residues were in the range of 90% (Barr *et al.*, 2007, p.12). Gold recovery results are highly dependent on the mineralogy of the ore for each project and the iron chemistry in the autoclave pressure leaching processes (Flemming, 2010, p.81). Results from MT pressure leach residues generated from enargite-rich residues are currently being evaluated at the pilot scale.

4.2.2 Process Selection

The process selection is not intended to be fully exhaustive and the selection of the appropriate option is ultimately impacted by several project specific factors that were not considered in this report. Nonetheless, for the purpose of this report, two competing options to Teck's CESL technology were highlighted based on recent studies and project developments. With the exception of differential flotation coupled with roasting, each of the alternatives

introduced in section 4.2.1 was included in a qualitative comparison. In the case of HT pressure leach there is evidence to suggest that copper recovery from high enargite bearing concentrates could be lower than MT pressure leaching. As well, higher capital and operating costs are realities of a total oxidation process (i.e. HT pressure leaching) compared to lower temperature oxidative processes (e.g. MT pressure leaching) (Kappes and Gathje, 2010, p.2046). This can be attributed to the full conversion of sulphur to sulphate in the HT pressure leaching process, which requires ~3 times more oxygen consumption (Flemming, 2010, p.82). The sulphide oxidation reaction is highly exothermic (Flemming, 2010, p.82) so HT pressure leaching will require a larger operating vessel than MT leaching. Roasting of high arsenic copper-rich gold ores (e.g. Barrick's El Indio Mine) was a preferred option for several years and in some cases it is still favoured by some (Dreisinger, 2005, p.13; Flemming, 2010, p.81). However, despite some advantages over HT and MT pressure leach processes, it has fallen from favour largely due to tougher environmental regulations relating to gas phase emissions, particularly arsenic oxide and sulfur dioxide (Dreisinger, 2005, p.13; Flemming, 2010, p.81).

When compared to roasting, copper recovery for MT pressure leaching may also be higher. Estimated copper recovery to a partial roasted calcine product has been reported to be lower than pressure hydrometallurgical options (Baxter and Scriba, 2010, p.1794). A more challenging issue with concentrate roasting are the high realisation costs that could raise the cost of production above that of pressure leaching which produces LME copper cathode (Baxter and Scriba, 2010, p.1799) compared to a partially roasted sulphur poor calcine product. The subsequent reagent requirements for arsenic fixation process can be very costly (Baxter and Scriba, 2010, p.1794/5). As well, not all of the arsenic is rejected from the calcine product allowing for potential marketing challenges on top of the loss of 'free' sulphur fuel due from the calcinations process. Table 4-3 summarizes the findings from the process selection discussion. Based on process alternatives analysis in section 4.2.1, Teck's CESL technology was selected as the preferred option for treatment of high-enargite bearing copper concentrates. Both HT pressure leaching and roasting are possible alternatives worth considering for treating high arsenic copper concentrates but the CESL technology option offers reasonable advantages over each of these technologies.

Table 4-3: Qualitative Comparison of Process Options for Enargite-Rich Concentrates

Criteria	CESL MT Pressure Leach	HT Pressure Leach	Concentrate Roasting
Commercial	All unit operations proven commercially, Vale UHC plant; not on enargite concentrates	Technology proven commercially for copper concentrates; not on enargite concentrates	Technology commercially proven on enargite concentrates
Metal Recoveries Enargite concentrate	>95% Cu with possible challenges; >90% Au; <90% Ag	>95% Cu with possible challenges; >90% Au; <90% Ag	Typically >95% Cu/Au/Ag to calcine product, can be lower depending on flowsheet
Arsenic Fixation	Scorodite in autoclave; no secondary unit operation required	Scorodite in autoclave, with possible challenges; no secondary unit operation required	Scorodite; separate hydrometallurgical process or HT Pressure Leach; some arsenic remains in calcine
Capital Cost Estimates	~3800-5400 US\$/t Cu	~4900-5600 US\$/t Cu	~1500-3000 US\$/t Cu
Operating Cost Estimates	~24-37 ¢/lb Cu	~39-44 ¢/lb Cu	~31-43 ¢/lb Cu
Realization Costs	Low - (no TC/RCs), Freight for Cu cathode	Low - (no TC/RCs), Freight for Cu cathode	Very High - (TC/RCs), Penalties for As remaining in calcine, Freight for acid, Calcine
Payables	High - LME grade cathode, plus market premiums	High - LME grade cathode, plus market premiums	<100% for Cu in Calcine, Variable markets

The range of unit capital and operating costs estimates expressed for the HT concentrate leaching and the concentrate roasting options in Table 4-3 are based on values previously presented in recent papers highlighting technologies available to process high enargite bearing copper-gold concentrates (Baxter and Scriba, 2010, p.1794; Peacey et al., 2010, p. 1044). The range of CESL unit capital and operating costs were extracted from a recent paper (Baxter and Scriba, 2010, p.1794) as well as some internal conceptual estimates (i.e. desktop studies) factored from historical data generated from past engineering studies. It should be noted that project capital and operating costs will likely vary considerably depending on site specific project information (e.g. geography and climate) including the mineralogy of the concentrate.

For the purpose of the conceptual financial evaluation undertaken for the TBL assessment in Chapter 5 for Project Cu-As, the CESL Cu-Au refinery unit capital and operating costs will be US\$4600/t of Cu and 31¢/lb Cu.

4.3 Peru: Copper

The recent and impressive growth in Peru's mining sector is significant and is an integral component of its economic growth and development. Peru's Mines and Energy Ministry (MEM) recently announced that they are expecting to approve up to 16 Environmental Impact Statements (EIS) for mining projects by July 2011 with a total portfolio valued at US\$41 billion (Andina, 2011). Aside from the economic activity these mining projects bring to Peru, there are equally important social and environmental considerations, which are essential to the sustainable development of these projects. Despite its deep-rooted history in mining and strong government support for mining, Peru has experienced extensive community and environmental issues central to the growth and development of its mining and exploration projects (Joyce, 2010, PDAC; Bebbington and Williams, 2008, p.190; Superneau, April 2010, p.2). Conflicts over the demand for water is a major issue for mining projects, which will not only lead to higher operating costs but also inevitably result in greater investments in the communities miners operate in order to maintain their 'social license to operate' (Superneau, April 2010, p.5; Stratos, 2008, p.20).

In order to effectively assess the viability of the Project Cu-As in Northern Peru using the TBL assessment, a better understanding of mining costs and refining capacities in this region of Peru is required. As well, knowledge of the associated social and environmental issues will be essential, especially during such high growth periods. Having said that, the aim of section 4.3 is twofold; first, to provide the relevant cost information with respect to copper mining and refining matters as it relates to Peru. Secondly, to identify major environmental and social issues that are central to mining and refining of copper in Peru.

4.3.1 Mining

Peru's mining sector is very important both regionally and on a global scale, specifically when it comes to copper mine supply. With some of the largest and lowest cost copper mines and projects in world (e.g. Antamina, Las Bambas); a large pipeline of resource opportunities; significant geological exploration potential; a pro-mining government; and favorable investment platform, Peru easily ranks as a leading global mining district in Latin America (Ernst & Young, 2010, p.10; Global Business Reports, 2008, p.78). In early 2009 Peru had approximately 12 major copper projects in development representing a total estimated investment of US\$10.7 billion (Mujica, July 2009, p.8). This was rather impressive considering Chile, the world's largest copper producer, had an estimated investment for the years 2009 to 2012 of US\$17 billion (Mujica, July 2009, p.8). Today the outlook for Peruvian mining remains very promising with a number of

mines due to start up soon. Investment incentive is very strong for Peru as indicated in a recent survey by Business News Americas which indicated that 87% of respondents said the climate was right for investment in Peru (Superneau, November 2010, p.15). Peru also ranks first in its region for best legal and regulatory framework (Ernst & Young, 2010, p.18).

Peru has extensive copper reserves and they rank second only to Chile's wealth of reserves. As shown in Table 4-4, Peru accounted for 11% of the world's reserve base in 2009 making it a leading source for future mine supply (Table by author, data sourced from Superneau, May 2010, p.16).

Table 4-4: World Copper Reserves and Reserve Base 2009 USGS Data

In millions of metric tonnes	Reserves	%	Reserve Base	%
Chile	160	29%	360	36.0%
Peru	60	11%	120	12.0%
Mexico	38	7%	40	4.0%
Indonesia	36	7%	38	3.8%
United States	35	6%	70	7.0%
China	30	5%	63	6.3%
Poland	30	5%	48	4.8%
Australia	24	4%	43	4.3%
Russia	20	4%	30	3.0%
Zambia	19	3%	35	3.5%
Kazakhstan	18	3%	22	2.2%
Canada	10	2%	20	2.0%
Other countries	70	13%	110	11.0%
World total (rounded)	550	100%	1000	100%

Exploration budgets are a leading indicator of future mine supply and Peru ranked on top of all Latin American countries in 2009 with 7% of the global non-ferrous exploration budget (excluding uranium) and according to Business News Americas, this trend is expected to continue through 2011 (Superneau, May 2010, p.17; Superneau, November 2010, p.15). In terms of mine site project costs there are distinct differences between South America and the rest of the world. Cash costs are lower in South America largely due to a higher number of large-scale, open-pit mines that brings the unit cost average down (Superneau, May 2010, p.19). Peru is expected to deliver average mine site costs that are far below Chile, Australia, Canada, and the world average

(Superneau, May 2010, p.23). A breakdown of the average C1 cash costs for Peru copper mining projects is shown in Table 4-5 (Table by author, data sourced from Wood Mackenzie, 2011).

Table 4-5: C1 Cash Costs for Peruvian Copper Mines

Copper Mine C1 Cash Costs – Peru (Wood MacKenzie Q1 2011 data)	
Cost to concentrate	97¢/lb Cu
Freight	7 ¢/lb Cu
Realization costs	14 ¢/lb Cu
By-product credits	(45 ¢/lb Cu)
Total C1 Cash Cost	72 ¢/lb Cu

For the purpose of the financial evaluation undertaken for the TBL assessment in Chapter 5, a mine cost to concentrate of 97 ¢/lb Cu will be applied for Project Cu-As. Because the concentrate is going to be fed directly to the CESL hydrometallurgical refinery, no significant mine site concentrate freight or realization costs are required for the mine to metal assessment. By-products credits for Project Cu-As will be accounted for accordingly in the financial analysis.

Capital intensities for copper projects have seen considerable escalation since 2005. This increase is best illustrated in Figure 9 below comprised of data from Brook Hunt and presented at Copper 2010 in Hamburg, Germany June 2010 (Figure by author, data source from Coombs, 2010, p.2112).

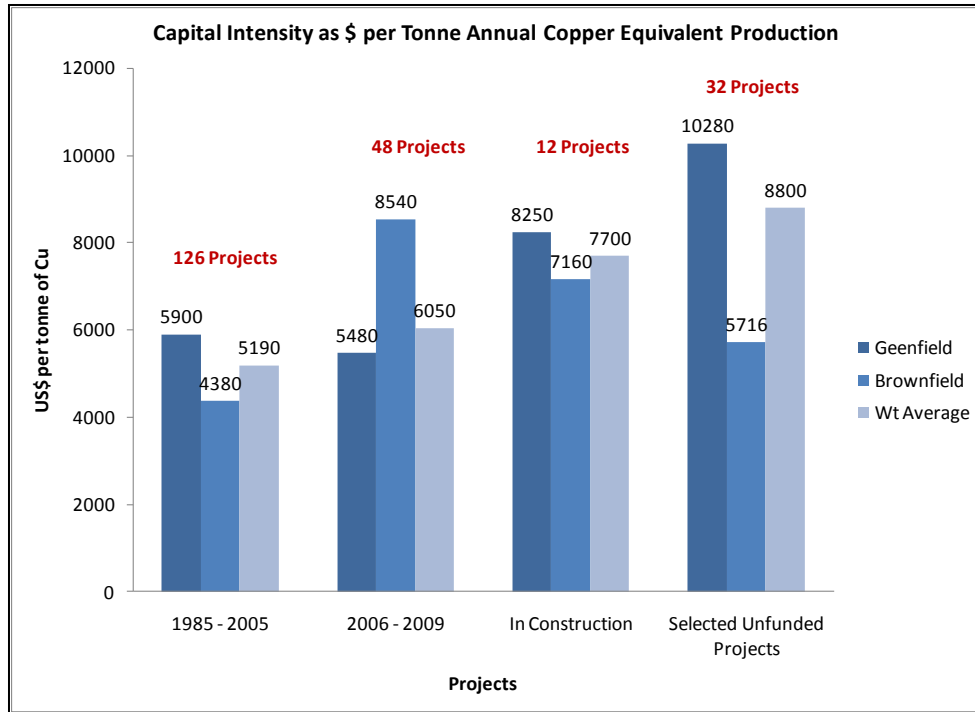


Figure 9: Capital Intensity Trends – Copper Mines (Brook Hunt Data 2010)

From a sample pool of 32 Greenfield projects, a capital cost intensity of US\$10280/t of Cu was determined. This compares relatively well to the US\$10890/t of Cu capital cost intensity derived from the seven Peruvian copper projects list in Table 2-1. For the purpose of the financial evaluation undertaken for the TBL assessment in Chapter 5, the copper mine capital intensity of US\$10280/t of Cu will be used. It should be noted that project capital costs will likely vary considerably depending on site specific project information (e.g. geography and climate). These changes will impact project financials significantly.

4.3.2 Refining

Peru's copper refining capabilities mainly reside at the Ilo smelter (280kta Cu capacity), which is owned by Grupo México via subsidiary Southern Copper and integrated with the company's nearby Toquepala and Cuajone mines (Superneau, September 2010, p.6). Peru is also home to the La Oroya polymetallic smelter (60kta Cu capacity) owned by US company Doe Run (Brook Hunt Global Copper Concentrate and Blister/Anode Markets, 2010, p.195). However, it has been shut down since the first half of 2009 due to economic and environmental problems, and it is unclear when it can reopen (Superneau, September 2010, p.6). Most of La Oroya's feed was

complex and it treated low-grade copper concentrates high in arsenic ranging from approximately 1.5% with maximum levels of about 6% (Brook Hunt Global Copper Concentrate and Blister/Anode Markets, 2010, p.195). According to Brook Hunt, Doe Run is required under the Peruvian PAMA environmental legislation to invest US\$120 million over five years in La Oroya. This investment will be required in order to upgrade its furnace technology and acid plant, and these changes will likely result in a reduction in the amount of arsenic it will handle (Brook Hunt Global Copper Concentrate and Blister/Anode Markets, 2010, p.195).

There is political interest for Peru to grow and modernize its concentrate refining capabilities. In January 2011, Peruvian presidential candidate Alejandro Toledo stated he would transform the economy from an exporter of raw materials to a producer of products with added value if elected for the second time (Dube, 2011). Toledo was Peru's president from 2001 to 2006 and is vying for presidency in April 2011. During this same speech, he claimed it was time for Peru to break away from being exporters of raw materials and begin investing in science, technology and innovation to transform Peru's production processes (Dube, 2011). As it stands, Peru's copper refining capabilities are limited and most of its concentrates are sold in the concentrate market. In 2010, Peru ranked behind Chile as the world's largest seller of copper concentrates at 13% of the total global supply (Brook Hunt Global Copper Concentrate and Blister/Anode Markets, 2010, p.27).

4.3.3 Environmental Considerations

Peru's competitive mine site cost structure and current lead in Latin American exploration, position it very well for future growth in copper projects. As well, there is clear need and desire for Peru to expand its refining capabilities beyond where they sit today if they wish to become producers of metal. All this is positive but there are fundamental environmental matters related to project development that merit consideration. The scarcities of water and energy sources have become critical issues for mining companies to consider in project development. Water rights and supply management is the most important issue when it comes to the extractive industry in Peru. This matter is discussed further in section 4.3.4. With the high growth in mining projects Peru is experiencing, energy supply will be a critical issue going forward. As it stands most of Peru's energy is generated from clean and renewable hydroelectric power stations. Thermoelectric (fueled by natural gas) power stations also supply considerable energy for Peru (Superneau, July 2009, p.2). With a growing number of mining projects, tailings and waste treatment designs will be vital in the quest for environmentally friendly mining and in Peru. As

well, improved materials stewardship is required to gain better control and understanding of the impacts of products. The use of industry best practice approaches for managing these issues is the right thing to do and it will help secure and maintain a miner's license to operate (Critical Resource, 2011, p.29).

In a January 2011 statement by former president Alejandro Toledo, the environment is a central issue for the extractive industry (Dube, 2011). Peru can award extractive companies with judicial stability, but they need to protect the environment (Dube, 2011). Export Development Canada (EDC) has over 30 years experience working in the Peru. Recently retired EDC President and CEO Eric Siegel noted in a 2008 Peru Mining seminar that not all mining companies have reputable records in Peru (Stratos Inc, 2008, p.2). Challenges still exist in Peru with respect to the responsibility of poor environmental legacies from historic sites and for the infrastructure required for new mines (Stratos Inc, 2008, p.2). The Energy and Mines Ministry (MEM) is the highest-ranking agency and their dual role of promoting and regulating the industry is seen as a conflict of interest that has generated a reasonable level of controversy (Stratos, 2008, p.18; Superneau, April 2010, p. 12). MEM ultimately decides on the approval of a project EIS (Stratos Inc, 2008, p.18; Superneau, April 2010, p. 12). With the growth of Peru's mining sector many feel this would best handled by Peru's recently created Environment Ministry (May 13, 2008) (Stratos Inc, 2008, p.18). Peruvian government officials will need to work with industry to ensure the country's environmental regulatory standards are held to the highest possible standards. During the same 2008 seminar for Mining in Peru, Mr. Pablo de la Flor, Vice-President Corporate Affairs for Compania Minera Antamina SA, reiterated that one of Peru's leading challenges was that its environmental standards have been inadequate and their enforcement has been uneven (Stratos Inc, 2008, p.4). These comments only emphasize the importance of the proactive involvement from both the environment ministry and individual mining companies towards improving environmental standards for Peru mining projects.

Mitigating environmental impacts of mining projects are always going to be front and center for any mining project in Peru. At a fundamental level, this involves the measuring and reporting on air quality, biodiversity, climate change, water consumption, greenhouse gases, and waste and land reclamation (Deloitte 2011, p.5). For the purpose of the TBL assessment it is convenient to think of these measurements as core environmental indicators, however they are intimately linked to the communities in which mines operate. For example, mining often competes with agricultural water rights making it the most important socio-environmental conflict in Peru (Superneau, April 2010, p.4). Failure to adhere or deliver sound environmental

performance standards will negatively influence the net benefit a mining operation can provide to the local communities and its indigenous peoples.

4.3.4 Social Considerations

Peru's economic history is strongly rooted in mining. Its national government is supportive of investments in mining as it generates more than 60% of Peru's export revenues, over 6% of its GDP and provides economic activity to some of the country's most remote and poorest communities (Superneau, April 2010, p.4). This fact has made it difficult for local community groups and indigenous peoples opposed to mining to be heard, often forcing them to resort to more violent protests (Superneau, April 2010, p.12; Bebbington and Williams, 2008, p.190). There are common beliefs and concerns that mining does not offer an equitable share of benefits to local communities or indigenous peoples; rather investment in mining causes pollution to water resources, agricultural land, and people (Superneau, April 2010, p.9; Bebbington and Williams, 2008, p.190). Such pollution will ultimately cause degradation of biodiversity which can reduce the supply of other natural resources (e.g., water, fish, or wildlife), and impact negatively on income sources for local populations (Bishop *et al.*, 2004, p.6). Mining companies and Peru's central government can partly attribute these beliefs to historical failures in their efforts to recognize the rights of the inhabitants of rural mining communities and indigenous peoples (Stratos, 2008, p.19). It is therefore not surprising that socio-environmental conflicts, as shown in Table 4-6, are the most common type of conflict in Peru, accounting for almost half of the reporting conflicts (Table by author, data sourced from Superneau, April 2010, p.3).

Table 4-6: Social Conflicts in Peru 2008

Social Conflict	Frequency (2008)	%Distribution
Socio-environmental	93	47
Local government issues	28	14
National government issues	19	10
Union / labour	15	8
Municipal issues	11	6
Land demarcation	9	5
Regional government issues	8	4
Electoral	6	3
Illegal cocoa farming	4	2
Other	4	2
Total	197	100

In Peru, sourcing water resources for mining projects is a leading cause of socio-economic conflict (Bebbington and Williams, 2008, p.190; Superneau, April 2010, p.3). In March of 2010 current President Alan Garcia established regulations on use and control of water resources which will be managed by the national water authority ANA stating water is a human right that cannot be bought or sold (Superneau, April 2010, p.5). Conflicts between communities and mining companies will likely continue as long as people feel their water supply is threatened (Bebbington and Williams, 2008, p.195). Mexico's Southern Copper's Tia Maria project in southern Arequipa is an example of a large scale project that has been temporarily suspended over water supply conflicts (Superneau, April 2010, p. 7).

Despite a strong investment incentive for exploration and mining in Peru, a recent survey by Business News Americas indicated that more than half (58%) feel social conflicts are likely to intensify in 2011, indicating that maintaining a social license to operate will remain a challenge and an area companies need to improve upon (Superneau, November 2010, p.15). Well-known examples of projects stalled in the past by protests include the Tambogrande (Manhattan Minerals) and Rio Blanco (Monterrico Metals plc) projects in Northern Peru (Superneau, April 2010, p.2). As in the case for Tia Maria, despite the promise of employment and improved infrastructure, communities neighboring mining projects will firmly reject proposed development plans on the grounds these projects could pollute their local environment and water sources (Superneau, April 2010, p.4). It has been frequently discussed within industry that early engagement by mining and exploration companies with all stakeholders including local communities, indigenous peoples, NGOs, and all levels of government is important to build trust and safeguard a company's social license to operate (Stratos Inc, 2008, p.20). One of the largest challenges threatening a miner's social license to operate in Peru is the lack of an official procedure or effective framework for structuring discussions with local communities and indigenous peoples (Superneau, April 2010, p.2). Without significant support from the central government agencies, mining companies are forced to organize their own public hearings to engage local communities about their projects which can lead to misunderstandings if the right mechanisms are not in place or if the process is rushed (Superneau, April 2010, p.12; Stratos Inc, 2008, p.20).

Mining companies are among the highest taxpayers in Peru, and as a result contributions to the economy from their activities are considerable (Dietsche, 2007, p.9). In Peru a percentage of the income tax revenue collected by the central government from mining activity is called the mining canon (Superneau, April 2010, p.10). These funds are distributed directly to regional and

local governments of areas where mining takes place. The mining canon came into effect in 1997 and in 2002 it was increased from 20% of a miner's income tax to 50%. (Superneau, April 2010, p.10). The mining canon funds are invested (100%) into public projects through the distribution presented in Figure 10 (Figure by author, data sourced from Superneau, April 2010, p.10).

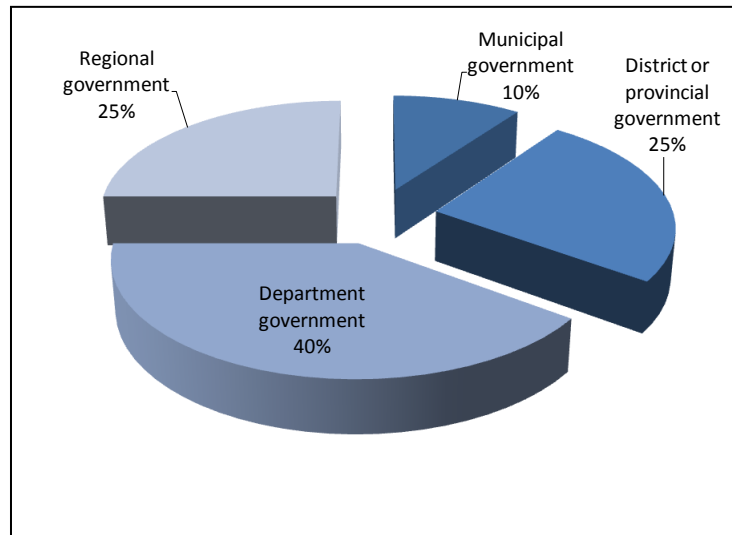


Figure 10: Distribution of Mining Canon 2010

However, despite having relatively transparent tax system (i.e. the mining canon system) local government administrators appear to be limited in their ability to deliver on projects that will provide infrastructure development and primary services to communities in mining districts (Superneau, April 2010, p.10; Stratos Inc, 2008, p.20; Dietsche, 2007, p.38). In many cases, miners are seen as the people who are responsible for delivering these basic services as they are on the ground in the local communities developing their projects (Dietsche, 2007, p.38; Superneau, April 2010, p.12; Stratos Inc, 2008, p.20). Gerald Wolfe, chief executive of Toromocho for Chinalco noted companies operating in Peru often find themselves filling the gap left by central government (Wade and Velez, 2010, p.98). These expectations are unfair and central governments along with mining companies need work together to ensure mining canon funds are effectively dispersed towards infrastructure and community development initiatives. In situations where the community is ill-equipped to manage an infrastructure project, assistance should come from government and or industry to maintain positive relations with the community.

As well, infrastructure developments that are not as easily visible by communities need to be well communicated and explained.

Despite the social issues that are inevitably an integral part of managing exploration and mining in Peru, many communities welcome mining. There are several large projects in Peru such as the Yanacocha mine (owned by Buenaventura and Newmont), the Antamina mine (owned by a consortium consisting of BHP, Mitsubishi, Teck and Xstrata) and the Tintaya mine (owned by Xstrata) that have been well-received and are collaboratively working with their respective communities to establish a common vision for the future of mining in their districts (Bebbington, and Williams, 2008, p.193; Dietsche, 2007; Superneau, April 2010, p.13). Successful junior exploration companies have also been recognized for their effective engagement with local communities while advancing their early stage project. In the Lambayeque region of northwestern Peru, Vancouver based Junior Exploration company Candente Copper has received strong recognition for their community work in the advancement of their Cañariaco Norte copper project (Candente Copper Corp, 2006). Examples of other notable large early stage copper projects in Northern Peru where respective companies continue to engage with local communities on their progressive development include Anglo American's Michiquillay, Lumina Copper SAC's (a subsidiary of the China Minmetals Corp. / Jiangxi Copper Corp.) Galeno project, and Rio Tinto's La Granja project.

Mining will continue to be an integral component of Peru's economy as is has been for many years. The social aspects of mining in Peru will remain an important element to advancing the development of projects. During a presentation at the 2011 PDAC, Carlos Diez Canseco, a mining consultant noted that the percentage of social investments from companies have increased since 2007 as they have learned that the social component of mining is a critical element to project development (Canseco, 2011). While these efforts may have contributed to improvements in mining company-community relations over the years, there appears to be considerable room for improvement at the governmental and corporate level. Specifically, this involves more effective distribution of income generated from the mining sector to meaningful community projects including adequate technical support for the completion of these projects. Mining companies and government need to implement successful communication and participation strategies so nearby communities and local indigenous people can understand the benefits of a mining project and can voice their concerns (Wade and Velez, 2010, p.98; Stratos Inc. 2008, p.21).

5: Triple Bottom Line Assessment

The following chapter details the TBL assessment for Project Cu-As. Information gathered from the market and industry analysis is applied in the assessments. The objective of the TBL assessment process is to equally consider the economic, environmental and social values added (+) or subtracted (-) by the integrated mine-mill-refinery operation. In doing so, key financial, environmental and social indicators related to the defined scope of Project Cu-As are developed and discussed. Comments specific to relative risks, confidence and or certainties are provided.

5.1 TBL Reporting Indicators

The TBL reporting indicators selected for Project Cu-As were profiled in section 3.2.1 (Figure 6). Each of the TBL indicators will be assessed qualitatively and or quantitative in the proceeding sections 5.1.1 to 5.1.3. Each of the assessments will be used to generate a ‘relative score’ for Project Cu-As in section 5.1.4 to establish the feasibility of the overall project.

5.1.1 Financial Assessment

The indicators used to established the financial value of Project Cu-As included: Resource Quality (RQ), Production Growth (PG), Profitability (P), and Product Marketability (PM). The selected measures for each of the indicators are listed in *Table 5-1* along with a summary of the qualitative and or quantitative analysis.

Table 5-1: Financial Indicator Performance Summary

Indicators	Measure	Qualitative / Quantitative Analysis
Resource Quality	Size, By-product credits, Complexity	Large open-pit design, moderate grades, appreciable by-product credits (Au, Ag, Mo), low strip ratio, ~24 years mine life, high arsenic (enargite) rendering concentrate unsalable to smelters, requires alternative refining technology (e.g. pressure oxidation).
Production Growth	Expansion Potential	Excellent regional exploration potential, several local projects challenged by arsenic, potential for industry partnerships and synergies with other projects.
Profitability	EBITDA, NPV, IRR, FCF	Integrated Mine-Mill-Refinery operation is profitable (refer to Table 5-2) using the assumptions within this report.
Product Marketability	Payable metal value	<p>Production of LME grade copper cathode is favored over marketing of high arsenic bearing concentrates or low sulphur calcine products containing notable arsenic.</p> <p>Significant penalties beginning at 0.2% As and or rejection by smelters of high arsenic bearing copper concentrates (>0.5%As).</p> <p>Low sulphur calcine product from concentrate roasters are susceptible to very high realizations costs.</p>

The quality of the resource is comparable to similar moderate grade Andean style copper-gold porphyry systems in Northern Peru district. The project has Au, Ag, and Mo by-product metals, which adds appreciable value to the project (i.e. ~15% of revenue stream). Widespread arsenic present throughout majority of the deposit precludes the project from conventional concentrate sales to smelters. A large open-pit design with a low strip ratio benefits overall mine site costs. The overall mine life is very good approaching 24 years. The ability to grow production is highly probable with excellent regional exploration potential in Northern Peru and opportunities to generate long-term feed sources for the refinery. The profitability of Project Cu-As was calculated using a simple financial model generated from the production assumptions presented in Table 3-1 and key inputs from the market and industry analysis of Chapter 4. Table 5-2 summarizes the financial performance of Project Cu-As.

Using the specific cost assumptions outlined for Project Cu-As, all indications point to positive profitability measures with long-term potential to guard against rising realization costs in the concentrate sales market with on-site refining. This should be regarded as a positive considering a concentrate with arsenic levels more than double the rejection limit (0.5%As) by conventional smelters is not marketable or saleable. Subsidies for Chinese smelters have allowed them to charge miners low treatment and refining charges (TC/RCs) and still be profitable (Superneau, September 2010, p.10). These subsidies are likely to change forcing Chinese smelters to raise TC/RCs in order to return a profit (Superneau, September 2010, p.10). Certainty around

product marketability is very good with the production of LME copper cathode compared to sales of high arsenic bearing concentrates susceptible to high penalties or rejection >0.5%As or low sulphur calcine products from concentrate roasters exposed to high realizations costs.

Table 5-2: Project Cu-As Financial Performance Summary

Project Financial Summary	
Metal Price Assumptions	US\$2.50/lb Cu, US\$850/oz Au, US\$18.00/oz Ag, US\$10.00/lb Mo
Project Life	~24 years
Project Capital Cost	~US\$2.5bln
Operating Cost	US\$1.42/lb Cu (ore to cathode)
EBITDA	~517mln US\$/yr
NPV (@ 8% discount rate)	~1.6bln US\$
IRR	14%IRR
Free Cash Flow (pre-tax)	~455mln US\$/yr

5.1.2 Environmental Assessment

The indicators used to establish the environmental value of Project Cu-As included: Energy and Greenhouse Gases (E&GHG), Land Use Impact (LUI), Waste Generation (WG), and Water Consumption (WC). The selected measures for each of the indicators are listed in *Table 5-3* along with a summary of the qualitative and or quantitative analysis.

Table 5-3: Environmental Indicator Performance Summary

Indicator	Measure	Qualitative / Quantitative Analysis
Energy and Greenhouse Gases	Total GJ/t Cu	Energy requirements for Project Cu-AS are estimated around ~44 GJ/t Cu.
	Total t CO ₂ (e)/t Cu	Total CO ₂ (e) for Project Cu-As are estimated around ~2.9 t CO ₂ (e)/t Cu.
Land Use Impact	Biodiversity Loss and Ecosystem Decline	Corporate programs are required to ensure social and economic development activities do not lead to further loss of biodiversity and degradation of ecosystem services.
Waste Generation	Quality of Tailings and Waste Rock	Potential issues such as acid generating rock needs to be factored into suitable tailings and waste rock impoundments. Manageable and should not complicate project development. Low strip ratio.
	Leach Residues and Effluents	Thermodynamically stable scorodite leach residue from hydrometallurgical CESL refinery can be stored separately with design measures in place to guard against potential long-term destabilization. Virtually no effluent.
Water Consumption	Fresh Water m ³ /tCu	Total fresh water consumption for Project Cu-As is estimated around ~176 m ³ /t Cu. CESL refinery can use seawater in leach process.

The total estimated unit energy requirements for Project Cu-As ~44 GJ/t Cu compared well to an industry average estimated value of ~40 GJ/t Cu for copper mining and concentrate shipping to a smelter for copper cathode production. The industry average value was comprised a mine site unit energy value of ~23.1 GJ/t Cu and a copper smelter and electrorefining value of ~16.9 GJ/t Cu (Farrell, 2009, p.29; Grimes *et al.*, 2008, p.13). The resulting greenhouse gas value for Project Cu-As ~2.9 t CO₂(e)/t Cu were slightly better than an industry average value for combined copper mining, shipping concentrate, smelting and refining ~3.33 t CO₂(e)/t Cu. The industry average value was comprised a mine site unit value of ~2.45 t CO₂(e)/t Cu and a copper smelter and electrorefining value of ~1.25 t CO₂(e)/t Cu (Farrell, 2009, p.29; Grimes *et al.*, 2008, p.13). A given mine site unit energy value will vary depending on the amount of rock that is required to be mined and the grade of ore processed. As well, corresponding greenhouse gas emissions (GHGs) will vary depending on fuel type (i.e. hydroelectric, natural gas, diesel, gasoline, coal). In this particular situation, energy requirements and total GHG production for Project Cu-As are comparable to industry standards and perhaps slightly better.

Biodiversity conservation is an integral part of any extractive industry project. A biodiversity policy should be geared towards no net harm to biological diversity, assure the conservation of habitats, flora and fauna, ensure maintenance, and where possible enhancement (e.g. net gain) of biodiversity (Dickinson, 2010, New Caledonia Nickel Conference). Such performance has been demonstrated at Teck operations. In 2009, Teck's Teck Highland Valley Copper Partnership and its Coal Mountain Operations each received a major environmental award for site reclamations, from the British Columbia Technical Research Committee on Reclamation (TRCR) (Teck, 2009). Teck is a responsible steward of the land they manage. With a proper management strategy in place, operations at Project Cu-As can have a net positive impact on biodiversity and ecosystems.

Large open-pit mines such as the one proposed in Project Cu-As yield substantial quantities of waste rock and tailings, which need to be managed with respect to the potential impacts to the land and water resources. Given the low strip ratio (ore to waste) of 0.5 to 1 for Project Cu-As, a mining waste rock to copper produced value of ~332 kg/kg Cu will be generated. The total mass of dry tailings produced is estimated to be 32 million tonnes per year or ~215 kg/kg Cu. In situations where there are indications that tailings have the potential to be acid generating an area with the most satisfactory storage capacity, ground conditions, and least impact on local communities must be chosen. The overall cost of construction will vary depending on the site and its available conditions. The design and operation of the mine tailings

impoundment is an important element of the sites water management system. There are numerous engineering firms highly experienced in the design of tailings impoundment systems that use thickened and paste disposition technologies to the environmental footprint of the tailings storage facility while conserving water (Global Business Reports, 2008, p.108). Tailings management is a vital issue that will need to be managed but should not complicate Project Cu-As. The volume of waste residue generated from the CESL refinery is significantly less than the mine site waste rock and tailings. Unlike conventional smelting technology, which struggles with arsenic waste management, the CESL hydrometallurgical plant can process high arsenic copper concentrates and is expected to be able to produce thermodynamically stable arsenic bearing leach residue. As described in section 3.1.1, The hematite and elemental sulphur rich leach residue (i.e. high in arsenic as scorodite) and acid neutralized residue (i.e. gypsum) generated from the CESL refinery would be less than ~1% of the total mine waste rock and tailings produced from Project Cu-As. There are multiple storage options for the combined hydrometallurgical leach residue and gypsum waste products to limit the possibility of arsenic release to ground waters during long-term storage due to potential biological and or chemical activity. Suggested options include dry storage due to potential biological activity and storage in a dedicated lined and monitored facility (Baxter and Scriba, 2010, p. 1786). Co-disposal of the combined hydrometallurgical leach residue and gypsum waste products with mine tailings is an option that could be investigated for Project Cu-As as the refinery will be located nearby.

The total estimated fresh water consumption for Project Cu-As was 176 m³/t Cu. This value compares well with a traditional mine-mill-smelter option value of 180 m³/t Cu. This value is comprised of industry average values of 172 m³/t Cu for copper mining, 7.8 m³/t Cu for smelting, and 0.6 m³/t Cu electrorefining (Norgate and Lovel, 2006, p.333; Mudd, 2008, p.142). Based on these figure it can be stated that the fresh water requirements for Project Cu-As are comparable to industry standards and perhaps better. Every effort will be required to reduce the unit freshwater consumption at the minesite and refinery (i.e. efficiencies or use of saltwater) as constraints on water supply should be expected. The associated costs of reducing fresh water consumption (e.g. increasing energy usage – desalination) must be considered. (Mudd, 2008, p.142) Nonetheless, a company's license to operate will be highly depended on an effective water management strategy.

5.1.3 Social Assessment

The indicators used to establish the social value of Project Cu-As included: Employment Generation (EG), Skills Development (SD), Community Impacts (CI), and Health and Safety (H&S). The selected measures for each of the indicators are listed in *Table 5-4* along with a summary of the qualitative and or quantitative analysis.

Table 5-4: Social Indicator Performance Summary

Indicator	Measure	Qualitative / Quantitative Analysis
Employment Generation	Number of Jobs	An integrated mine-mill-refinery project would create significant employment opportunities in Northern Peru. The estimated number construction jobs would be ~2500 and the estimated number of fulltime production jobs would be ~1000
Skills Development	New Jobs Training	A hydrometallurgical copper refinery in Northern Peru would create a number of highly skilled labour jobs and diversify Peru's refining industry beyond traditional pyrometallurgical operations (i.e. Ilo and La Oroya) Potential for establishing new refined products industry with production of copper metal in Peru (i.e. semi fabricated products and casting products)
Community Impacts	Income Taxes (mining canon)	50% of the income tax revenue collected by the central government (i.e. mining canon) will flow directly to regional and local governments for capacity building. Estimated average mining canon of ~\$US35 million/yr for the first 9 years increasing to ~\$US89 million/yr
Health and Safety	Air Quality (Dust and Emissions) Bioaccessibility and bioavailability values for arsenic Product and Reagent Toxicity (Physical and Toxicological Properties)	Dust management program required for mine site. Use of hydrometallurgical refinery eliminates SO ₂ generation and fugitive emissions from traditional pyrometallurgical roaster or smelter routes. Engineering / operational and exposure controls (e.g. ventilation, containment of material, process control) to protect workers. Impacts on community health should be monitored. Low solubility and toxicity for refined copper metal. (Vale Inco, 2009) No extensive shipping of hazardous concentrates. Multiple chemicals and reagents (i.e. cyanide, HCl, H ₂ SO ₄) at the mine site and the refinery need to be managed carefully.

An estimated number of construction and fulltime operating jobs can be derived new developments such as Xstrata's Las Bambas (400k tpy copper) and Antapaccay (160k tpy copper) projects.(Xstrata Copper, 2010; Xstrata Copper, 2011) Approximately 2500 construction and 1100 fulltime operating jobs (~70% at the minesite, ~30% at the refinery) could be expected from Project Cu-As. These jobs will generate considerable income within the Northern Peruvian communities where Project Cu-As would reside.

A significant number of highly skilled labour jobs will be included within the ~300 CESL hydrometallurgical refinery jobs. The construction of a refinery in Northern Peru producing copper cathode may also motivate the establishment of further industries involving semi-fabricated products or castings from copper metal. Project Cu-As could be highly simulative to the economy of Northern Peru if additional downstream manufacturing businesses are created.

The income tax revenue generated from Project Cu-As will be considerable for the local communities. Assuming an income tax rate of ~40% (Ernst &Young, 2010, p.20) the estimated average annual mining canon would be ~\$US35 million during the first nine years of the project when most of the capital is depreciated. Throughout the remaining years of Project Cu-As, the estimated average annual mining canon would likely triple, reaching closer to \$US90million.

Peru's health and safety regulations are in the process of being redrafted (2010) by Ministry of Energy and Mines as the result of high annual fatality rates personnel (i.e. 56 fatal accidents in 2009, 64 in 2008) (Randle *et al.*, 2010, p.9) A focus will be put on job specific personnel selection and induction processes for new employees. (Randle *et al.*, 2010, p.9) Worker safety and health is the number one issue at every Teck operation as it would be for Project Cu-As. Dust management is common problem at minesites. There are best practice approaches to managing dust at minesite and it is not expected to be a major issue for Project Cu-As. Unlike concentrate roasters or smelters, the CESL hydrometallurgical refinery will have no harmful fugitive or sulphur dioxide (SO₂) emissions. Engineering controls are put in place to guard against potential exposure to arsenic at the refinery and this can be tracked and monitored through biomonitoring and bioaccessibility results. With respect to product toxicology, copper cathode poses little to no harm due to its low toxicity and solubility. Proper management of chemicals and reagents at the minesite and refinery will be required. Although the use of cyanide for gold leaching is common in Peru, a great deal of effort must be taken to communicate a cyanide management procedure for Project Cu-As to local communities, NGOs, and indigenous peoples. Companies such as Buenaventura and Newmont who are active leaders in the Peruvian gold mining scene can be good sources for developing such a strategy.

5.1.4 Final TBL Scorecard

In the following section Project Cu-As is scored using the information that was gathered and presented in the previous sections. The basic scoring system that will be used is outlined below in Table 5-5.

Table 5-5: TBL Scoring System

Major negative	Negative	Minor negative	Neutral	Minor positive	Positive	Major positive
-3	-2	-1	0	1	2	3

If any one of the financial, environmental, or social indicators are viewed as potentially performing below industry standards then they will be rated on the negative scale depending on severity. A neutral rating ('0') would mean Project Cu-As would be expected to perform at or near an industry standards. Above industry, performance would yield positive scores depending on the implied benefit. The scoring results for Project Cu-As is summarized in Table 5-6.

Table 5-6: Final TBL Scorecard Results for Project Cu-As

Indicators	Score	Cumulative Scores
Financial		Overall financial performance assessed as 'minor positive to positive'
Resource Quality (RQ)	0	
Production Growth (PG)	2	
Profitability (P)	2	
Product Marketability (PM)	3	
Environmental		Overall environmental performance assessed as 'neutral to minor positive'.
Energy Consumption and GHG Emissions (E&GHG)	0	
Land Use Impact (LUI)	1	
Water Generation (WG)	1	
Waste Consumption (WC)	0	
Social		Overall social performance assessed as 'positive'
Employment Generation (EG)	3	
Skills Development (SD)	3	
Community Impacts (CI)	2	
Health and Safety (HS)	1	
Total Score (Financial – Environmental – Social)	18	Overall TBL performance range assessed as 'minor positive to positive'
Average Indicator Score	1.5	

The total score given to Project Cu-As was positive 18. Equally weighting each of the 12 indicators would give Project Cu-As an average score of 1.5, which is below the positive rating of ('2') but above that of the minor positive rating of ('1') presented in Table 5-5.

5.1.5 Monitoring and Evaluating Performance

Spider diagrams are simple visualizations that can be effective tools when communicating the benefits of projects to key stakeholders (Esvelt and Karamysheva, 2006, p.12). The spider diagram in Figure 11 depicts the TBL assessment for Project Cu-As.

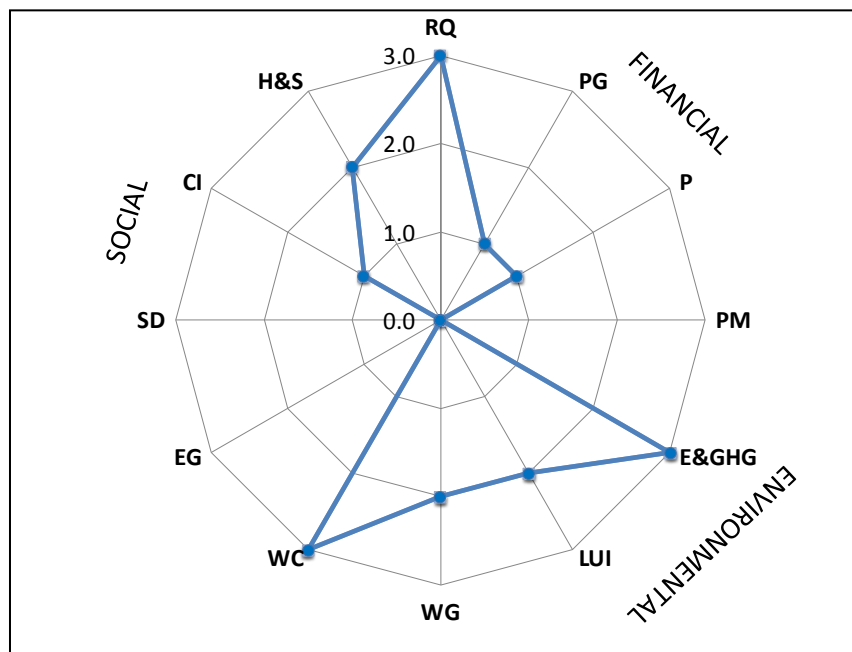


Figure 11: Spider diagram for Project Cu-As

Considering there were no clear negative values associated with Project Cu-As the scale for the spider diagram was adjusted to decipher the strength of the neutral to positive TBL scores presented in Table 5-6. Indicators closest to the centre are expected to be perform better (i.e. ahead of industry standards). Scores approaching the exterior boundary of the diagram are then approaching industry standard. Having said that the numerical scores were reversed in order to display this relationship between the indicators. If an indicator received a major positive score of

3 in Table 5-6, then it was assigned a ‘0’ rating within the spider diagram reflecting its expected strong performance above industry standards. This simple relationship is shown in Table 5-7.

Table 5-7: Spider Diagram Scoring Legend

Major negative	Negative	Minor negative	Neutral	Minor positive	Positive	Major positive
-3	-2	-1	0	1	2	3
6	5	4	3	2	1	0

The lowest performances were neutral ratings assigned to Resource Quality (RQ), Energy Consumption and GHG Emissions (E&GHG), and Water Consumption (WC). The neutral score for RQ was due to its high arsenic contents largely precluding it from development via conventional concentrate sales. However, its size, contained metal value, low strip ratio add considerable value. The availability of non-traditional refining technologies (e.g. pressure oxidation) that could unlock the value in this type of resource is enough to give it a neutral rating. The neutral scores for E&GHG and WC were allocated because unit values were comparable to current industry averages.

Indicators for Health and Safety (H&S), Waste Generation (WG), and Land Use Impact (LUI) were viewed as potentially outperforming industry standards but will require implementation of industry best practices to do so or better. The application of pressure hydrometallurgy offers some well documented H&S and WG advantages with respect to arsenic management compared to current pyrometallurgical options. Specifically, all of the arsenic departs to one leach residue in a thermodynamically stable form of ferric arsenate (i.e. scorodite) and there is no need for arsenic capture from multiple solid and gaseous streams with a separate and costly arsenic fixation stage. Teck’s record as a responsible steward of the land they manage was enough to assign a minor positive ratings to LUI.

The Profitability (P) of the project, Production Growth (PG), and overall Community Impact (CI) were seen as positives. Converting a copper resource precluded from development to due to high-arsenic contents into a tangible economic project is a positive. The financial assumptions (e.g. capital and operating costs, metal prices, currency etc.) were not rigorously tested in this report however and this is something that would be evaluated for a real project opportunity. With plenty of exploration potential in the region the growth of Project Cu-As

should be very promising. The tax revenues generated from the profit of Project Cu-As will have a positive stimulative impact to the communities living in proximity to the project. However, execution and success will hinge on positive collaborative efforts on behalf of the government and the mining company working with local communities and indigenous peoples.

Employment Generation (EG), Skills Development (SD), and Product Marketability (PM) all received the highest performance ratings (i.e. closest to the center of the spider diagram). Job creation along with skill development will be significant for Project Cu-As. Marketability of copper cathode production allows for smooth predictable earnings unlike high arsenic bearing concentrate or partially roasted calcine which are both exposed to high realization costs.

6: Conclusions and Recommendations

The final Chapter of this report will provide the conclusions and recommendations for the TBL assessment of Project Cu-As. Final remarks regarding the merits and viability of the Project Cu-As are given. Recommendations pertaining to the successful advancement of Project Cu-As are outlined.

6.1 Conclusions

Triple Bottom Line (TBL) thinking was utilized to assess the viability of an integrated mine, mill, and hydrometallurgical refinery operation for a hypothetical high arsenic bearing copper-gold deposit located in Northern Peru (i.e. Project Copper-Arsenic). TBL may not be an exact measurement tool but it proved to be an effective way of thinking and understanding the projects' performance with respect to potential financial, social and environmental outcomes. By equally weighting the potential value added (or subtracted) impacts from each of the financial, social and environmental indicators, a more holistic view of the Project Copper-Arsenic's performance was determined. More importantly, this endeavour shifted the sole focus from potentially short-term financial aspects only (e.g. net present value) to include the longer-term social, environmental and financial impacts. Therefore, expanding and utilizing TBL values beyond corporate or global industry reporting systems to include a simple but holistic assessment can help identify gaps or challenges within the key focused indicators of a project. Although TBL is not meant to replace well-developed legislative or regulatory processes such as Environmental and Social Impact Assessments (ESIA), it can help support decision-making that will ultimately influence a company's social license to operate and help move new projects toward more tangible stages of development.

Economic success in mineral extractive projects depends on a sound environment and healthy community. From exploration activities, to mining and metal processing, the development of high arsenic bearing copper resources must contribute to the sustainable development values outlined earlier in this report. The resulting TBL score from this report is not a specific measure of sustainability; rather it should be interpreted as a guide to help identify how Project Cu-As can progress towards sustainable development goals defined by company, industry, government, and

other key stakeholders. Based on the TBL assessment results compiled in this report, an integrated mine-mill-refinery approach using Teck's CESL copper hydrometallurgical refining technology was found to be a leading alternative for the development of high arsenic bearing copper resources. During the TBL assessment, no significant negative issues or challenges were uncovered. On average, the project scored positively for the financial, environmental, and social indicators. Project Cu-As demonstrated that it has the potential to contribute to the sustainable development values by creating shareholder wealth and helping to establish employment opportunities in the remote regional area of Northern Peru. The fully integrated operation (i.e. mine-mill-refinery) has the potential to build capacity in the region that would benefit from strengthening the skills and capabilities of its people for future infrastructure projects. With the adoption of industry best practices, all of this is possible while avoiding irreversible harm to the local environment.

6.2 Recommendations

Despite the identified potential for Project Cu-As as outlined in the TBL assessment, there are three recommendations worth considering to ensure the success of South American projects such as Project Cu-As. The first is to act decisively (Gurlit *et al.*, 2007, p.7). Mining is a long-term business and competition will be strong as there are numerous mining companies vying for copper resources to expand their pipeline of projects (Superneau, February 2010, p.10; CRU International Feb2010, p.3). By acting as a first-mover in the development of high arsenic copper resources Teck can capture a competitive advantage and expand its current portfolio of copper projects in South America. The second and most important recommendation is to go local (Gurlit *et al.*, 2007, p.9). Establishing local management on the project teams can be critical to timely advancement of a project in many emerging markets such as Peru (Gurlit *et al.*, 2007, p.9). Local management can play an integral role in the early engagement processes with local governments, communities, indigenous peoples, and NGOs. Establishing positive relationships with all stakeholders while actively involving them in the decision making process will be critical to a project's success in Peru. Finally, like any project in the extractive resources industry, Project Cu-As must be guided by industry best practices and standards in order to meet or exceed full environmental regulatory compliance measures when it comes to managing arsenic in copper mining and metal production.

Appendix

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Mean Rob CESL

From: Waller Greg VANM
Sent: Tuesday, April 19, 2011 3:13 PM
To: Mean Rob CESL
Subject: RE: Images from Teck's Investor Relations Presentations

Yes, ok to use. Should date source reference though as these have been updated since then in what we use in our IR presentations.

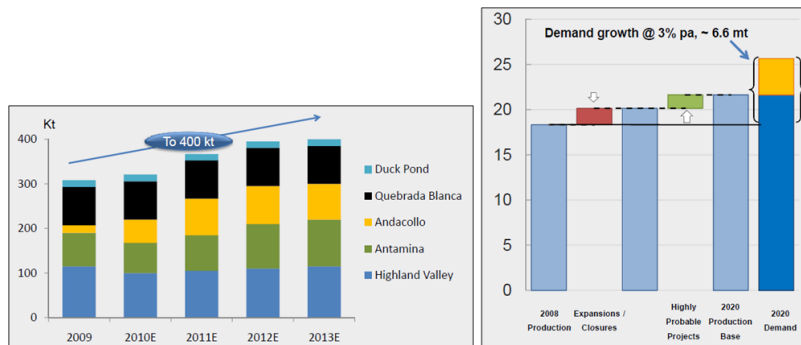
Greg Waller
 VP, Investor Rel & Strategic Analysis
 Teck Resources Limited

From: Mean Rob CESL
Sent: Tuesday, April 19, 2011 2:29 PM
To: Waller Greg VANM
Subject: Images from Teck's Investor Relations Presentations

Hi Greg,

I would like to inquire about using Teck's images/figures on slides 19 and 20 (referenced from Teck's BMO Capital Markets Presentation – 2011 Global Metals and Mining Conference) as part of my Executive Master in Business Administration final project at Simon Fraser University. The purpose for use of slide 19 is to highlight / describe the demand for new mine supply. The purpose for use of slide 20 is to highlight Teck's potential growth in their copper business. The project will be copyrighted in my name and a copy will be available at the University where it may be accessed by the public but it will not be available for distribution.

Sincerely,
 Rob



Permission to use figures from Teck Resources Limited – CESL Flowsheets

Mean Rob CESL

From: Defreyne Jennifer CESL
Sent: Tuesday, April 19, 2011 3:43 PM
To: Mean Rob CESL
Subject: RE: Flowsheet Images from Teck's CESL Presentations

Hi Rob:

Yes you may use the figures.

Jennifer

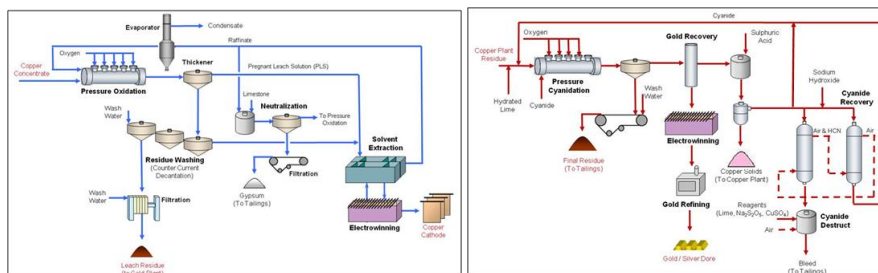
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From: Mean Rob CESL
Sent: Tuesday, April 19, 2011 2:55 PM
To: Defreyne Jennifer CESL
Subject: Flowsheet Images from Teck's CESL Presentations

Hi Jen,

I would like to inquire about using the following CESL flowsheet images/figures (shown below) as part of my Executive Master in Business Administration final project at Simon Fraser University . The purpose for use of these images is to describe Teck's CESL copper and gold flowsheets. The project will be copyrighted in my name and a copy will be available at the University where it may be accessed by the public but it will not be available for distribution.

Sincerely,
Rob



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