

**Development of a Copper Mining and Processing Educational Module
for a Tribal Community College**

By Jennifer Stanley
Report
Master of Agriculture Education
May 1, 2013

Table of Contents

List of Figures.....	3
List of Tables.....	4
Chapter 1: Introduction.....	5
Abstract.....	6
Introduction.....	6
Objectives.....	11
Chapter 2: Procedures.....	12
Procedures.....	13
Timeline.....	18
Chapter 3: Creative Component.....	19
Instructional Guide.....	20
Comprehensive PowerPoint Lecture.....	43
Chemistry Lab Excerpt.....	83
Hands-On Activity.....	83
Hands-On Activity Worksheet.....	89
Hands-On Activity Answers.....	91
Glossary.....	92
Chapter 4: Conclusion.....	93
Conclusion.....	94
References.....	96
Appendices.....	98

List of Figures

Copper, Copper Mining, and Copper Processing

Figure 1. Native copper from Ray mine, Arizona	21
Figure 2. Examples of copper containing minerals	21
Figure 3. Worldwide copper consumption in metric tons and per capita copper consumption in lbs, 1950-2010	23
Figure 4. Impact on the price of copper shown in red and operating cost shown in blue	24
Figure 5. Featuring the “5 C’s” upon which the state economy was founded on including cattle, cotton citrus, climate, and copper	25
Figure 6. Mine products produced in Arizona and highlighted locations of copper mines	26
Figure 7. Conceptual relationship of mineral resources and ore reserves	30
Figure 8. The process of crushing, grinding, and separation of copper once the raw materials are hauled to the copper mill	33
Figure 9. Process of heap leaching.	34
Figure 10. Process of solvent extraction.	34
Figure 11. P process of electrowinning.	35
Figure 12. Process of froth floatation.	36
Figure 13. Four processes that copper undergoes to be refined.	37
Figure 14. Copper anode slab after it is taken from a furnace to be molded in to 2 inch thickness, 3 feet wide, a height of 3.5 feet, 750 lbs in weight and is 99% pure copper.	38
Figure 15. The electrolysis process of a anode	38
Figure 16. Shows the process of what Copper goes through from mining to everyday usage.	39

Chemistry of Copper Electrolysis

Figure 1. Materials needed for copper electrolysis lab.	91
Figure 2. 33 cm length of 18-gauge copper wire.	91
Figure 3. A) Peelings apart red and black coated wires. B) Separated red and black wires.	92
Figure 4. A) Closed wire stripper; B) open wire stripper, and C) 1.5 cm length of rubber coating removed from copper wires to expose copper filaments.	92
Figure 5. A) Exposed copper filaments; B) twisted copper filaments; and C) final product of twisted and folded copper filaments.	92
Figure 6. A) Unattached copper wires and B) copper wires attached to alligator clips.	93
Figure 7. Red and black wire pushed through a cardboard with alligator clips attached.	93
Figure 8. Electrodes immersed in the electrolyte solution	94
Figure 9. A) Cross section illustration of final copper electrolysis lab set-up. B) Actual copper electrolysis lab set-up.	94
Figure 10. Diagram of commercial-scale electrolytic refinement.	96

List of Tables

Copper, Copper Mining, and Copper Processing

Table 1. 14 month project timeline	18
Table 2. Copper consumption by major markets in the U.S. in 2006	22
Table 3. The five stages of the life cycle of a mine and its associated period of time, cost, and cost per metric ton	28

Chemistry of Copper Electrolysis

Table 1. Determining the mass of copper plating	96
---	----

Chapter 1

Abstract

Educational modules are independently packaged units of study to enhance the learning process and can be modified and adapted to different learning scenarios and objectives. The benefits of educational modules are hands-on activities, incorporation of technology, student involvement, discussion, and exchange of ideas. Copper mining educational modules will be developed for the Tohono O'odham Community College (TOCC) to enhance the understanding of copper, copper mining, and copper processing. Modules will incorporate tribal perspective and needs to promote effective learning. Modules will be designed to augment the existing associate's of science program (Life Science Option or Tohono O'odham Agriculture and Natural Resources Option) currently offered at TOCC and can be modified for other tribal and non-tribal community colleges.

Introduction

Traditionally, the O'odham people occupied large lands in the Southwest spanning from Sonora, Mexico to central Arizona (Tohono O'odham Nation, 2012). Today, the Tohono O'odham Nation is the second largest reservation in Arizona and the United States with 2.8 million acres spanning across three Arizona counties. Tohono O'odham Nation has approximately 28,000 enrolled tribal members and their traditional name means "the Desert People". The traditional land of the O'odham people was divided by the United States border and today nine O'odham communities (approximately 8,400 tribal members) exist along the southern border of the Tohono O'odham Nation (University of Minnesota, 2006). Members have the right to travel freely across the international border to visit

family and practice religious and cultural practices, although they face the risk of unlawful deportation by U.S. border patrols. The average income on the reservation is \$7,000, annually and there are associated low high school graduation rates and health issues (over half the tribal members have type-two diabetes). The O'odham society was divided into four federally recognized tribes that include the Tohono O'odham Nation, Gila River Indian Community, Ak-Chin Indian Community, and Salt River (Pima Maricopa) Indian Community. They are connected by the O'odham language and culture.

Mining interests and activities have impacted the O'odham people since the mid 1800s and early on, led to the loss of O'odham lands south of the border (Tohono O'odham Nation, 2012.). Today, there are approximately 210 mines on the Tohono O'odham reservation within Pima County (Arizona Geological Survey, 2012). Most of the mines have been abandoned from lack of money and/or small-time prospectors. Out of the 100 biggest mining companies in the world, two of them are in Arizona. Freeport-McMoRan Copper & Gold (#8) and Southern Copper (#13) are both based out of Phoenix, Arizona. One of the major mines in Arizona, Cyprus Tohono Mine, is located on the reservation . It is owned by Freeport-McMoRan Copper & Gold. The two most publicized mines are the Silver Bell and the Tohono mines. The Silver Bell mine is not located within the Tohono O'odham Nation, however, it is very close to its border. The Silver Bell mine produced approximately 237.4 million pounds of copper from 2003 to 2007 with an average of 47.5 million pounds per year (Niemuth, 2007). This mine is of concern due to its environmental and health hazards that may have impacted the Tohono O'odham people. The Tohono mine shows a record of producing 5.2 million pounds of copper in 2006 and 3.0 million pounds in 2007 (Niemuth, 2007). Other metallic minerals have been mined on or near the Tohono O'odham

reservation including gold, copper, silver, lead, zinc, polymetallic, iron, mercury, manganese, uranium, and tungsten (Arizona Geological Survey, 2012). Five places of concern regarding mining impacts on the Tohono O'odham Nation are the Sif Oidak District, San Xavier District, Lakeshore, Allison, and Pisinemo. Millions of dollars have been generated for the tribe, along with royalties, through mining leases in the Sif Oidak District. Three chemical operations and major ongoing joint venture mining continue on the reservation. According to the Reclamation in Arizona, Freeport-McMoRan Company ensures environmental compliance related to air, water, noise, dust and local permitting, by working closely with EPA Region 9 and the Tohono O'odham Nation.

The Tohono O'odham Nation believes that education is the key to the success of their tribe and will result in higher income, lower unemployment, improved health, increased tax revenues, lower crime rates and improved civic life for their community (Tohono O'odham Nation, 2012). As a result, the Tohono O'odham Nation created the Tohono O'odham Community College (TOCC) in 2000 to promote the education of students and to create a stronger work force by offering certificate programs (liberal arts, business, science, and Tohono O'odham studies), associate's degrees (liberal arts, business, sciences, social services), direct employment programs (agriculture and natural resources, business, child development, administration, social services) and apprenticeships (various construction trades such as carpentry and plumbing). TOCC is a two year institution accredited by the North Central Association of Colleges and School. TOCC requires all enrolled students to take the Tohono O'odham language course so that the Tohono O'odham culture and language can be preserved. TOCC strives to create programs designed to incorporate cultural teachings and has a policy called the Himdag Policy that requires all

students and faculty to teach and study to preserve the culture, language and history of the O'odham people. In the fall of 2009, the full-time enrollment reached 255 students.

An educational module entitled "Copper, Copper Mining, and Copper Processing" was developed for Tohono O'odham Community College students (particularly those in sciences and agriculture and life sciences) to understand copper mining, copper processing, and its impact on humans and the environment. Educational modules are independently packaged units of study to enhance the learning process and can be modified and adapted to different learning scenarios and objectives. The benefits of educational modules are hands-on activities, incorporation of technology, student involvement, discussion, and exchange of ideas. This module was designed to augment existing associate's of science program (Life Science Option or Tohono O'odham Agriculture and Natural Resources Option) currently offered at TOCC and can be modified for other tribal and non-tribal community colleges. The strength of this project was to develop educational modules that will teach tribal educators, tribal students, and tribal community members about the mining industry and the environmental impacts of mines. The goal was to teach tribal college educators the modules, which will be incorporated into the existing environmental sciences curriculum. Students will then have the opportunity to re-teach it in their community. They will also have the opportunity to become more involved in research and policy regarding mining themes.

The Superfund Research Program focuses on hazards in three areas: arsenic, chlorinated solvents, and mine tailings. The theme of the UA Superfund Research Program is "Hazardous Waste Risk and Remediate in the Southwest." SRP focuses on addressing health effects of contaminants that are of concern in the United States Southwest and along

the Mexico border. Within hazardous waste sites SRP looks to focus on characterizing, containing, and remediating the hazardous waste. SRP does a great deal of community outreach. The partnership with TOCC creates a great collaboration opportunity with SRP to develop mining and environmental educational modules for tribal colleges. The educational modules were developed to enhance the understanding of:

- Copper mining and processes
- Environmental impacts of mining
- Remediation techniques
- Mining exposure and risk.

The purpose of this creative component project is to enhance the understanding of the copper mining industry and the environmental issues that are related to mining on the Tohono O'odham reservation. The goal is to create a connection with TOCC to develop educational modules related to the mining issues stated above. These modules incorporate the copper mining industry, issues impacting the environment, and techniques to remediate waste that comes from copper mines. These modules are created to be implemented into existing classes offered at the Tohono O'odham Community College in the following subject areas; Science (Chemistry/Biology), History, and Environmental Science.

Objectives

The objectives are to:

- A) partner and work closely with the Tohono O'odham Nation and Community College to develop the educational module and to incorporate tribal perspective;
- B) conduct a literature review to assess current mining activities on the Tohono O'odham Nation;
- C) develop a detailed written instructional guide on Copper, Copper Mining, and Copper Processing;
- D) develop a comprehensive PowerPoint presentation that supplements the instructional guide;
- E) create a hands-on activity and identify technology tools to support the educational module;
- F) refine the educational module using reviews from a technical committee; and,
- G) present an excerpt of the educational module on "Copper Electrolysis" to a Tohono O'odham Community College chemistry class.

Chapter 2

Procedures

The objectives were accomplished through a series of steps. A model of a successful existing, transferable training module that informs Latino community health advocates (promotores) about environmental hazards made by Ms. Denise Moreno was used. By educating promotores, they can then re-teach what they learn to their constituency. A literature review was conducted covering the background of copper worldwide and in the state of Arizona; Tohono O'odham tribe; the mining process, and existing maps of the Tohono O'odham Nation. Literature was collected to help support educational modules in the classroom. Meetings were conducted with the Tohono O'odham Community College, Tohono O'odham Natural Resources Department, Tohono O'odham Nation Environmental Protection Agency, and Tohono O'odham Department of Mining. Multiple meetings were set up with instructors from TOCC to gain knowledge of the Tohono O'odham culture that was incorporated into the educational modules. The meetings helped build a connection with the University of Arizona and the Tohono O'odham Community College. Establishing this relationship with TOCC has broadened the network with existing tribal colleges in the state of Arizona. A hands-on activity was developed to go with the PowerPoint presentation as a way to develop a deeper understanding of the module.

Throughout the development of the module weekly meetings were held with employees of University of Arizona Superfund Research Program (SRP) to discuss the progress. The Superfund Research Program provided reviews and feedback on the Instructional Guide, hands-on activity and the supplemental PowerPoint presentation.

Members of the Superfund Research Program (SRP) include Dr. Raina Maier, Dr. Karletta Chief, Dr. Sarah Wilkinson, and Ms. Denise Moreno.

A visit to the Sierrita mine in April 2012 was conducted to gain a better understanding of the mining process and the importance of the process of mining copper and molybdenum in an open-pit mine. After gaining a wealth of knowledge about how the process of copper mining entails the educational module, the instructional guide, and the hands-on activity were created.

A meeting was held in May 2012 with Dr. Muhamud Farah, Mr. Gregory Redhouse, Dr. Teresa Newberry, Mr. Phillip Miguel, Dr. Casey Thornburgh, and Mrs. Juana Clare Jose from the Tohono O'odham Community College. This meeting served to gain their cooperation to collaborate with them on the educational module. A meeting was also held with Ms. Lorinda Sam from the Tohono O'odham Environmental Protection Agency. Ms. Sam knows about the environmental actions that were done to the mines on the Tohono O'odham reservation. These meetings were very helpful and vital to gain knowledge and perspective on mining.

In June 2012, the Copper Processing Module was presented to the Native American Science and Engineering Program (NASEP). NASEP is a program for high school juniors and seniors that are interested in Science, Technology, Engineering and Mathematics and are at the top of their class. This experience aided in developing the necessary presentation skills on how to deliver the module to a group of Native American students.

In August of 2012, a website called The Chemistry of Copper Plating was identified and the experiment found on the following website was modified for use with the module: <http://www.woodrow.org/teachers/ci/1986/exp30.html>.

During the weekly meeting with the SRP group, Dr. Maier allowed the materials from her lab to be used to create an electrolyte solution ($\text{CuSO}_4 \cdot 5\text{H}_2\text{O} + 25.0\text{mL H}_2\text{SO}_4$). Other materials, such as: 9 volt battery, 18 gauge copper wire (red and black), wire cutter, pliers alligator clips, vinegar, and salt were also acquired. A 250mL beaker from Dr. Maier's lab along with a 250 mL bottle container to transport the electrolyte solution was also utilized along with cups and cardboard from the SRP office. After collecting all the materials for the lab a test run was conducted to make sure the process worked. The lab experiment was a success. A guide was then created on how to conduct the experiment. Pictures were taken to use in the steps of the guide to avoid confusion of how to do the lab. This experiment was selected to give the students an idea of how an anode and a cathode work in an electrolyte solution similar to what happens during the copper processing. A PowerPoint presentation was also created that goes hand-in-hand with the steps of the lab procedure.

September 2012, a meeting was held with TOCC instructors: Mr. Redhouse, Dr. Newberry, and Dr. Farah regarding the copper mining and processing educational module. The first version of the copper mining and processing module was presented to the instructors. Feedback from each of the instructors was collected on the content of the module and a discussion of the plan on how the educational module would be included in their lesson plans for the upcoming academic year was held. The goal for this meeting helped developed a stronger partnership with UA Superfund Research Program and Tohono O'odham Community College so that the module could be tailored to fit the needs of TOCC. SRP and TOCC both agreed that once the module is complete, TOCC will have full ownership of the module and will have the ability to modify it if need be to fit TOCC's educational needs. It is understood that the module will continue to change and evolve.

The Tohono O'odham Natural Resources Department was contacted in October 2012 to set up a meeting with Mr. Addison Smith, Director of Mining of the Tohono O'odham mines and Ms. Lorinda Sam from the Tohono O'odham Environmental Protection Agency. Mr. Smith is very familiar with a majority of the mines located on the Tohono O'odham Nation. Building the relationship with the Natural Resource Department on the reservation was important to earning their respect to be able to work with them to create the educational modules. Meetings were conducted with Mr. Smith in Sells, AZ and in Tucson, AZ at the University of Arizona campus. The meetings provided Mr. Smith the opportunity to share his wealth of knowledge of mining. Mr. Smith was consulted to ensure that the correct information was used in a respectful way.

Experts from Freeport-McMoRan Copper and Gold, Tohono O'odham Nation Department of Mining, Geological Engineering at the University of Arizona, and Civil and Environmental Engineering conducted a technical review of each component the educational module. The experts were chosen based on their positions and their wealth of knowledge in their respective fields. These experts reviewed technical aspects of the educational module, including the instructional guide, supplementary PowerPoint presentation, and hands-on activity.

At the end of the month of October, a meeting with Mr. William Cobb, Vice President of Environmental Services and Sustainable Development at Freeport-McMoRan Copper and Gold was held. Freeport-McMoRan Copper and Gold was selected to be involved because their company owns the Tohono Cyprus mine. In the ending stages of completing the educational module, Mr. Cobb provided edits on the supplementary PowerPoint presentation based on his background in mining and knowledge of the Tohono Cyprus

mine. Dr. Poulton from the Department of Mining and Geological Engineering on the U of A campus is a Distinguished Professor and the Department Head. She was selected to review the instructional guide, and the supplementary PowerPoint presentation. Mr. Smith also gave a technical review of the educational module based on his background in mining on the reservation. The hands-on activity was sent to a graduate student, Mr. Delvin Tadytin from the Chemistry Department. Mr. Tadytin did a technical review of the hands-on activity encompassing the electrolytic process. Dr. Reyes Sierra also provided a technical review of the supplementary PowerPoint presentation. Dr. Sierra works in the Department of Chemical and Environmental Engineering.

After incorporating the edits of the experts a pilot presentation was given. Dr. Newberry from TOCC gave permission to do a presentation of the module in her Chemistry class in Sells, Arizona, in December 2012. Mr Smith was invited to attend the presentation and was in attendance the day of the lecture. During the presentation, a pre-survey and post-survey assessment was given using 5 questions. These five questions helped provide data on how much the students knew about copper before giving the presentation. The hands-on activity with the students in the Chemistry course was also conducted. The electrolysis as a hands-on activity was created because it is recognized that the students tend to be kinesthetic learners. The electrolysis component gives the opportunity to see the end results of the copper process. At the end of the presentation given at TOCC in Dr. Newberry's class, a post-survey with 5 questions to see if they comprehended the information in the module was administered. Mr. Smith was also given the opportunity to speak with the students on his background with the tribe and helped with the presentation by answering questions the students had. The presentation of the copper mining and

processing educational module and hands-on electrolysis activity was a success. The students at TOCC were engaged in the lecture and asked informative questions that created dialogue amongst their peers and the experts in the room. The students asked if they could keep the materials to the hands-on activity so that they can conduct the experiment when they have more time.

Timeline

This was a 14 month project that began October 2011 and ended December 2012.

Table 1: 14 month project timeline with action items.

ACTION	2011			2012										
	O	N	D	J	F	M	A	M	J	J	A	S	O	N
Lit. Review														
Modules														
Activities														
Mine Visit														
Refinement														
Printing														
Meetings														

Chapter 3

Project Product

Copper, Copper Mining, and Copper Processing

Learning Objectives

- Describe basic information about copper, its occurrence, and use
- Articulate the history and current status of copper mining in the United States, Arizona, and Tohono O'odham tribal lands
- List and describe the five stages of copper mining including prospecting, exploration, development, exploitation, and closure
- Describe copper processing for oxide and sulfide ores

Summary

Copper is a chemical element that has a variety of uses based on its properties of malleability and conductivity (Baxamusa, 2012). Copper ore deposits are found on every continent, and it has been mined around the world for more than 10,000 years. However, more than 95% of the copper in use today has been mined in the last century (Leonard, 2006). Copper is used in many modern products, from housing, to automobiles, to portable electronics (Crescent City Copper, 2011). The life cycle of a copper mine comprises of five stages: prospecting, exploration, development, exploitation, and closure/reclamation (Hartman & Mutmansky, 2002). Copper processing is a complex and labor-intensive process, as copper usually makes up less than 1% of the total volume of ore mined (Hartman, 1992). Copper can occur as oxide and sulfide ores and a series of unique physical, chemical, and electrochemical steps are used to separate and refine the copper to 99.9% copper from the ores. As a result of modern day uses of coppers and methods used to process copper to its useful form, copper mining and processing have both positive and negative impacts for the people and environment.

Copper, its occurrence, and use

A. What is copper?

Copper is a chemical element in the periodic table with the symbol **Cu** (from the Latin word *cuprum*, meaning 'metal of Cyprus,' where it was mined during the Roman era). Copper has an atomic number of 29 and atomic weight of 63.54. It is an element in Group 11 of the periodic table, along with silver and gold, which it shares many properties with. In its standard state at room temperature, copper is solid. Copper is reddish-orange and has a bright metallic luster. With weathering, copper can become coated in a dull green tarnish of

Copper
29
Cu
63.54

copper carbonate called verdigris. One famous example of this is the Statue of Liberty, which is coated with 60,000 lbs of copper sheeting that has weathered to a dull grey-green. Copper is relatively soft, and is malleable and ductile, meaning that it can be shaped or molded without breaking, for example, hammered flat into sheets or drawn into wires. Copper is resistant to corrosion, and is a good conductor of heat and electricity (second only to silver). In addition, copper is antimicrobial, meaning it resists growth of microorganisms, and has biomedical applications such as copper socks, handles used in hospitals, and tables used in kitchen restaurants. Because it is an element, copper can be perpetually recycled, without losing its properties. These properties can be adapted for specific uses based on whether it is used alone or alloyed (mixed with other elements). The most common copper alloys are bronze (copper and tin) and brass (copper and zinc), which are harder and stronger than copper.

B. Geologic Forms

Copper is found in the earth's crust as native (pure) copper, or in combination with other elements. Copper deposits were formed by volcanic activity and can be found around the world on every inhabited continent even Antarctica. Native copper may occur in crystal form, meaning its atoms are organized in a regular pattern, but more often copper is found as irregular masses or veins, which fill fractures or spaces in the earth's crust.



Figure 1. Native copper from Ray mine, Arizona (specimen 5.25 x 4 x 1 cm); native copper cementing host rock from Ray Mine in Arizona; and native copper specimen (source: http://en.wikipedia.org/wiki/Native_copper; http://en.wikipedia.org/wiki/Native_metal)

When found in combination with other minerals, copper can occur in forms such as copper sulfides (e.g. chalcopyrite and chalcocite), copper carbonates (e.g. azurite and malachite), copper silicates (e.g. chrysocolla), and copper oxides (e.g. cuprite) (Figure 2). Such copper ores can be very complex, containing a variety of other non-metallic minerals, as well as metals and other elements. Within an ore, copper concentration is often less than 1%. Each of the different natural forms of coppers requires a unique process to be made into pure copper as high as 99.9% copper.

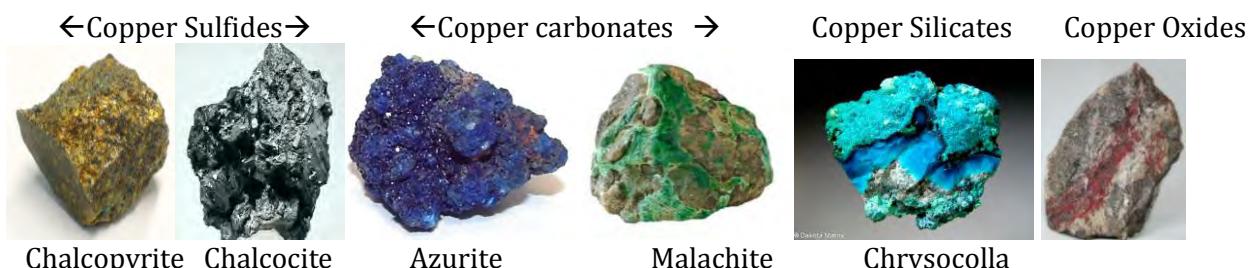


Figure 2: Examples of copper-containing minerals

C. Historical and Modern Copper Consumption

Copper has been used for thousands of years; it is estimated to have been discovered as early as 9000 BC in the Middle East. Early artifacts were made of native copper; prehistoric uses include utensils, tools, weapons, piping, ornaments, and jewelry. Copper smelting, or the use of heat and chemical reactions to extract a particular metal from an ore, appears to have been discovered independently in different parts of the world. A rise in the use of copper defines the Chalcolithic period (from the Greek words *khalkos* and *lithos*, meaning 'copper' and 'stone,' respectively), which occurred between the end of the Stone Age and the advent of the Bronze Age, approximately 3500-2500 BC. Smelting of ores containing both copper and tin likely led to the discovery of the alloy bronze, which is easier to cast, and allowed a greater variety of materials to be made, including figurines and vessels. The addition of zinc vapor via calamine ore allowed the production of brass, which became popular in the Roman world during the first millennium BC, often for decorative purposes. Copper's use as currency also came into prominence in the Roman world in 280 BC as brass coins and in 23 BC as copper coins. The development of copper has a rich history that spans to current times.

Today, copper and its alloys have a variety of uses that impact our daily lives. The five major uses of copper are (Table 1): construction (e.g. plumbing, electrical wiring); electronics (e.g. cell phones, computers); general consumer products (e.g. currency, cookware); industrial equipment (e.g. manufacturing machinery); and transportation equipment (e.g. cars, airplanes). To give some examples, the average U.S. built automobile contains 50 lbs of copper, and the average U.S. built home contains 400 lbs of copper. Copper alloys are also used to make important and common instruments and tools. For example, bronze (copper and tin) is used to make durable tools (e.g. hammers), musical instruments (e.g. bells and cymbals), ornaments, medals, statues, and bearings of various machines. In addition, brass (copper and zinc) is used to make musical instruments (e.g. trumpets and other horns) and decorative art, and low friction (e.g. locks and gears) and non-sparking tools (e.g. for use around explosive gases). Copper and its alloys are used in numerous applications by a diverse set of economic sectors.

Table 2: Copper consumption by major markets in the U.S. in 2006. Source: Freeport-McMoRan.

Type of Market	% Copper Consumption	Copper Consumption [million lbs]	Examples
Construction	50.6%	3,946	Wiring and plumbing
Electronics	19.3%	1,500	anything with an on/off switch
General Consumer Products	10.7%	829	Household appliances, etc.
Transportation Equipment	10.5%	814	Cars, trucks, trains, etc.
Industrial Equipment	8.9%	691	Power plants and

Worldwide consumption has steadily increased over the past 60 years (Figure 3). In 1950, the worldwide consumption of copper was approximately 3 million metric tons, which grew rapidly to 18 million metric tons in 2010. If the copper products used in the U.S. in one year were made into one long copper wire, it would circle the earth 2,530 times. The increase in worldwide consumption is not due to an increase in world population alone; and the per capita copper consumption has also increased (Figure 3) due to different rates of household and technological uses. In 1950, the average person used 2.5 lbs of copper, compared to 6 lbs of copper per person in 2010. A person born today is expected to use 1,398 lbs of copper in his/her lifetime. From 1900 to 2010, using 2009 dollars, the price of copper decreased from approximately \$4.60 to \$2.50 (Figure 4). The decline in the price of copper parallels a decline in the operating costs, and likely reflects advancements in technology that have improved the efficiency of copper mining. The graph can be misleading when using world per capita consumption. World capita consumption brings down the world average when used due to disparity between two nations. (Hammond, 2012)

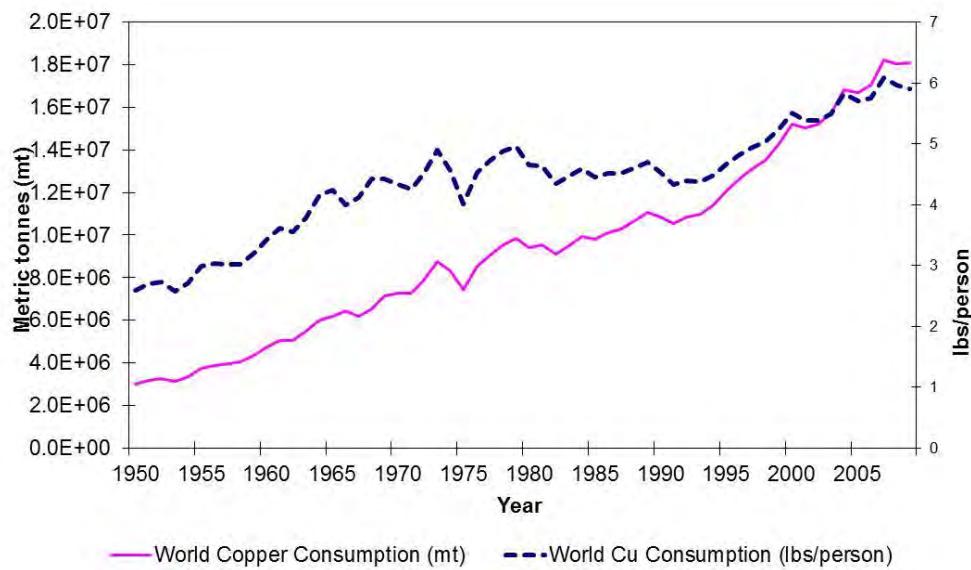
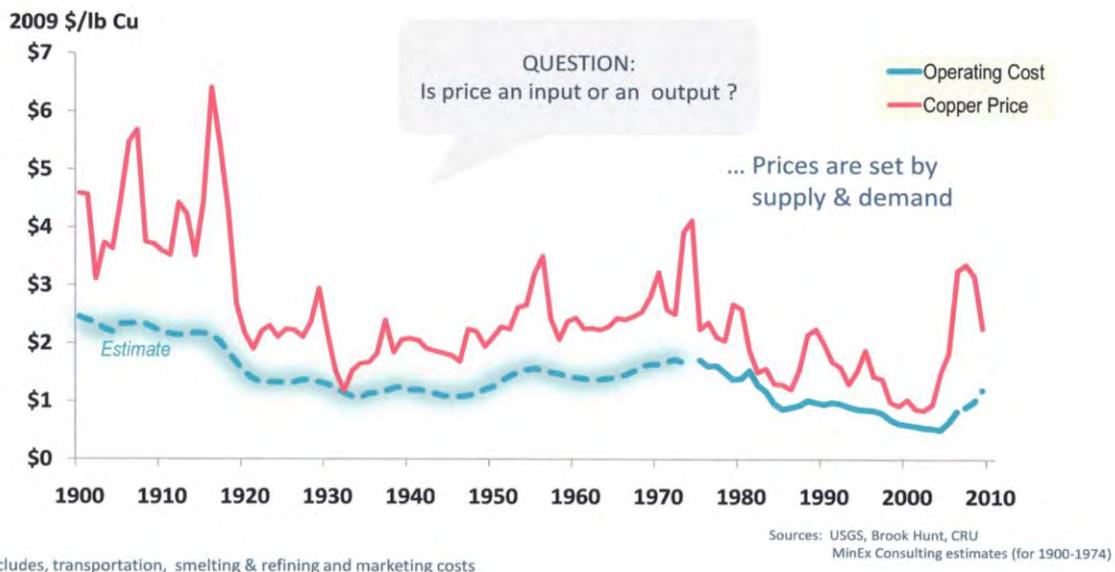


Figure 3: Worldwide copper consumption in metric tons (pink line) and per capita copper consumption in lbs (blue line), 1950-2010. (Hammond, 2012)

Over the last 100 years, the real price and cost of copper has halved

Copper price and (estimated) average operating costs for Western World: 1900-2009



MinEx Consulting

Strategic advice on mineral economics & exploration

21

Figure 4: Impact on the price of Copper shown in red and operating cost shown in blue (dotted line depicts an estimate of operating prior to 1975) (Hammond, 2012) (USGS, Brook Hunt, CRU, MinEd Consulting estimates (for 1900-1974)

D. Copper mining in the United States, Arizona, and Tohono O'odham lands



The largest deposit of native copper discovered to date was found in Michigan at the Keweenaw mines. Native Americans mined copper in this area between 5000 and 1200 BC, as evidenced by copper knives, arrow, spear heads, and axes found in the area, but it was not mined on a commercial scale until the 1840s. Copper has been produced worldwide for a number of years. The top three producing countries in the world are Chile, Peru, and United States in the year 2010. In 2010, Chile produced 5,418,900 metric tonnes of copper, Peru produced 1,247,126 metric tonnes of copper, and the United

States produced 1,129,300 metric tonnes of copper. In the United States, Arizona produces the largest amount of copper at the Morenci mine with 380,000 tonnes a copper in 2009. Arizona has 14 major copper mines that have or are producing copper, with two mines under development to open. Twelve of the major copper mines are located in the south-

east part of the state. Four of the copper mines are located near or on the Tohono O'odham reservation. The United States is the second largest producing copper country in the world, second to Chile. Approximately 98% of mined copper come from five states in the U.S; Arizona, Utah, New Mexico, Nevada, and Montana, respectively.

Arizona has a rich history of copper mining, exploration, and use. Subsequently, copper is showcased as one of the “5 Cs” on the Great Seal for the State of Arizona upon which the Arizona economy was founded: cattle, cotton, citrus, climate, and copper (Figure 5).



Figure 5: Featuring the “5 C’s” upon which the state economy was founded on including cattle, cotton, citrus, climate, and copper.

Out of the 100 biggest mining companies in the world, two of them are in Arizona: Freeport-McMoRan Copper & Gold and Grupo Mexico (Allison, 2011 and Niemuth, 2011). The Morenci mine, owned by Freeport-McMoRan, is one of the largest mines in the United States. More than 20 major mines contribute to the Arizona economy today – 14 of these are copper mines, including two which are in the process of trying to open. Most of the copper mines are located in the southeastern part of Arizona (Figure 5). Arizona is directly and indirectly impacted by the copper mining industry meaning copper mining creates jobs (indirect) and functionality (direct) for electronics, plates, wires, jewelry etc. The copper industry generated \$4.6 billion in 2000 and \$12.1 billion in 2010, with Arizona producing 63% of the copper in the U.S. In addition, the copper industry generated 73,100 jobs for the Arizona economy.



Figure 6: Mine products produced in Arizona and highlighted locations of copper mines.

In Arizona, 21 federally-recognized tribes own lands that cover 19.7 million acres, or 27%, of the state. Many of these tribal lands in Arizona contain mines such as coal, copper, uranium, lime, and cement to name a few. Sacred lands (on and off the reservation) of tribes in Arizona and across the United States are protected by U.S. laws and include:

- 1938 – Indian Mineral Leasing Act
 - Land needs to go through approval from the tribal council or an authorized spokesperson of the tribe to be leased for mining purposes. Giving tribes the

right to practice self-determination by giving them a voice to decide what to do with resources located on tribal land.

- 1978 – American Indian Religious Freedom Act
 - The Religious Freedom Act serves to protect and preserves the right of freedom for American Indians to believe, express, and exercise traditional religions, and also to protect access to sacred sites and the freedom to worship ceremonial and traditional rites.
- 1982 – Indian Mineral Development Act
 - This act was enacted to meet two objectives: to promote the stance on self-determination and to increase the economic return that tribes can anticipate for their valuable mineral resources.

Of the 72.9 million acres of Arizona land, 2.7 million acres, or 3.7%, belong to the Tohono O'odham tribe. Metallic minerals mined on or near the Tohono O'odham reservation include: gold, copper, silver, lead, zinc, iron, mercury, manganese, uranium, and tungsten. There are approximately 210 metallic mineral mines, prospects and quarries within the Pima County portion of the Tohono O'odham Nation. However, many of the smaller mines are the results of small-time prospectors and have been abandoned. On the Tohono O'odham land there are 4 major metallic mineral mines: Reward mine which is a historic mine, Allison which is a silver mine no longer operating, Tohono Cyprus (Lakeshore) copper mine has gone through a restoration plan and environmental assessment in October 2012 (DOI, 2012) and Mission mine at San Xavier is a copper mine that is currently operating. In addition, the Silverbell mine is located right near the Tohono O'odham border. Silverbell mine is not located on the reservation but it does have direct and indirect impacts on the tribe.

Cyprus Tohono and the Silverbell are two large copper mines that have positive and negative impacts for the Tohono O'odham Nation. The Cyprus Tohono Mine, near Casa Grande, AZ, is located on land leased from the Tohono O'odham Nation. In 2006 and 2007, Cyprus Mine produced 5.2 and 3.0 million lbs, respectively, of copper from sulfide minerals. In 2007, reclamation work has been done on Cyprus mine. Reclamation included moving materials from old tailings impoundments and evaporation ponds to a new area that is protected. The new site was re-seeded with native vegetation from the area. The second mine is Silver Bell mine which is not on the Tohono O'odham reservation but is located very close to its border. This mine has produced more 237 million lbs of copper from 2003 to 2007, and is of concern due to environmental and health hazards that may have impacted the Tohono O'odham people (Niemuth, 2007). In 2010 Silver Bell mine suffered a rupture in a pipeline that caused highly acidic solution to spill 70,000 gallons into a dry wash (Associated Press, 2013). Places of interest on the reservation include: Lakeshore, Allison, Pisinemo, San Xavier district, and Sif Oidak district, where millions of dollars have been generated for the tribe, through mining leases. Mission mine located on the south end of the San Xavier land covering 5,124.15 acres, near highway I-19 is still active and is operated by ASARCO (Gault Group, 2008). It is approximately 2.5 miles long, 1.5 mile wide, and 1,200 feet deep situated on 20,000 acres of land. Reclamation has been 75% completed at the Mission Mine on the Tohono O'odham San Xavier District (Klempel, 2013).

Rosemont mine located just south of Tucson is in the final stages of getting permitted to open. Mining company, Augusta Resource Corporation proposes to open Rosemont mine in 2015 to make it the 4th largest copper mine in the United States. A feasibility study was done on the mine and concludes that the mine would be open for 21+ years to produce an approximately 243 million lbs of copper per year, at a price of \$1.02/lb of copper. Rosemont mine has a copper/molybdenum reserve, looking to produce 5.9 billion lbs of copper and 194 million lbs of molybdenum.

E. Life Stages of a Mine

There are five stages in the life cycle of a mine: 1) prospecting, 2) exploration, 3) development, 4) exploitation, and 5) closure/reclamation. Each of the stages may overlap with the next. Each step in the process is very lengthy and expensive; it is estimated that the odds of actually opening a mine at the end of the first four stages range from 1: 1,000-10,000.

Table 3: The five stages of the life cycle of a mine and its associated period of time, cost, and cost per metric ton.

Stage	Time	Total Cost	Cost per Metric Ton
1) Prospecting	2-8 years	\$0.5 - \$15 million	9¢ - \$1.40
2) Exploration			
3) Development	4-12 years	\$10 - \$250 million	23¢ - \$4.50
4) Exploitation	5-30 years	\$5 - \$50 million per year	\$1.80 - \$90.00
5) Closure/Reclamation	10-15 years 35 years	\$5-15 million \$50 million	NA

i. Stage 1 - Prospecting

Prospecting and exploration are precursors to mining and often occur simultaneously; together, they can take 2-8 years to complete, and may cost from \$0.5 to 15 million overall. Prospecting is the process of searching the region for mineral deposits. Historically, prospectors would explore a region on foot with a pick and shovel. Modern prospecting uses a variety of geological methods. Geology experts use a direct method to discover surface mineral deposits by examining the area visually. Geophysics is used as an indirect method to identify underground mineral deposits by detecting rock alterations under the surface. Geochemistry can also be used to analyze samples of soil, rock, and water. These methods are supplemented by aerial or satellite photography, and combined with historical maps and literature to develop detailed maps of surface and underground rock formations and structures. Experts do some drilling to record the position/location of the finding, to determine the type of rock and to determine the depth of the rock source. Information gathered in this stage may or may not lead to a discovery of valuable minerals.

ii. Stage 2 - Exploration

The second stage of mining is called **exploration**, where experts use additional techniques to determine the possible size and value of the mineral deposit discovered during

prospecting. Purchase of a lease to mining rights may be done at this time. Samples are collected by drilling and then undergo various analyses by geologists and mining engineers to determine the richness and extent of the mineral. There are two different types of drilling: diamond drilling and rotary or percussion drilling. Diamond drilling is used to produce cylindrical core samples and is more useful, but also more expensive. The less expensive rotary or percussion drilling accounts for 70% of exploratory drilling, and produces chips or cuttings. The samples are then examined and evaluated for mineral content. This allows experts to establish an economic value of the ore and to estimate mining costs.

Following the completion of the prospecting and exploration stages, a **feasibility study** is performed to determine whether it is economically worth developing the mineral deposit into a mine. A feasibility report is generated, in which factors such as production rate, operating costs, income tax, and the sale price of the mineral are estimated and put into a formula to calculate what the final rate of return will be. The mining organization can then make a decision about whether the project will be abandoned or continued at this stage. A key aspect of the feasibility study is the categorization of the deposit as a mineral resource or an ore reserve.

To justify whether an area should be mined, experts first determine if the area can be distinguished as a Mineral resource. A **Mineral resource** is a concentration of potentially valuable material that naturally occurs in the earth that can be mined for economic profit. (**Minerals** are naturally occurring inorganic solids with a crystalline structure and a definite range of chemical formula.) Whether it is worth extracting may depend on the amount, form, location, and quality of the material, a concept called geological confidence. Experts use geological knowledge to classify a mineral resource into three different categories: 1) inferred, 2) indicated, and 3) measured which correspond to low-level to high-level geological confidence (Figure 4, Hartman, 1992).

1. **Inferred** – *low* level of confidence based on amount (extent), quality, mineral content. This information is gathered from trenches, pits, drill holes, outcrops through appropriate testing techniques. Bottom line: might be there but not sure.
2. **Indicated** – *reasonable* level of confidence based on amount, densities, shape, physical characteristics, quality, and mineral content. Through exploration, testing and sampling of the mineral, information is gathered from trenches, pits, outcrops, and drill holes. Geological and grade continuity cannot be confirmed because locations of the resources are too widely or inappropriately spaced. Bottom line: has been sampled, but still only an estimate.
3. **Measured** – *high* level of confidence depending on amount, densities, shape, physical characteristics, quality, and mineral content. Measured mineral resource is determined based on reliable and detailed exploration, along with sampling and testing information that is gathered from trenches, pits, outcrops, and drill holes. The locations of where these techniques are gathered from are spaced closer together than an indicated mineral resource to confirm its geological and/or grade continuity. Bottom line: additional sampling – an expert thinks the estimate is accurate.

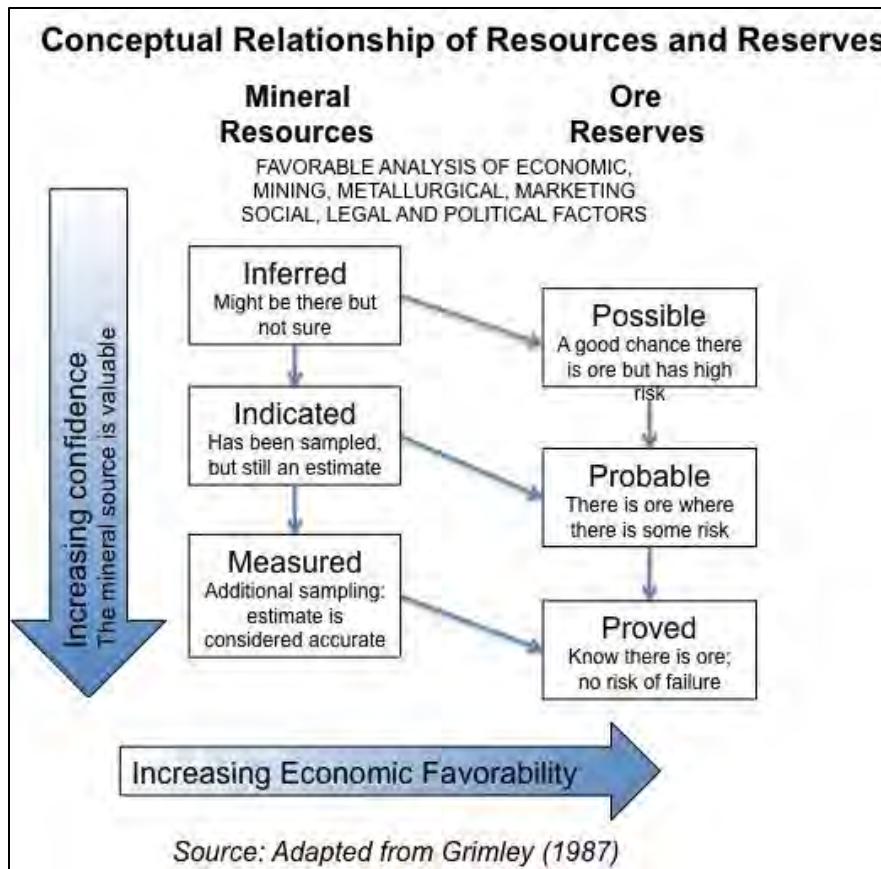


Figure 7: Conceptual relationship of mineral resources and ore reserves (Grimley, 1987).

An **ore reserve** is a subset of the measured and indicated mineral resources, which can be economically profitable to be mined. (**Ores** are concentrations of minerals in a rock that are high enough to be economically extracted for use.) After a material has been classified as an indicated or measured resource, it can be further identified as 1) possible, 2) probable, or 3) proved ore reserve based on factors determined by an expert (Figure 6). Probable ore reserves come from indicated mineral resources and proved ore reserves come from measured mineral resources.

1. Possible – A preliminary feasibility study is conducted on inferred mineral resource to determine if there is a good chance there is an ore deposit. At this stage there is still a little confidence that the ore is valuable giving it a high risk of failure to happen.
2. Probable – A preliminary feasibility study is conducted on indicated and measured mineral resources to determine if economic extraction of an economical minable part can be justified, at the time of reporting.
3. Proved – A preliminary feasibility study is done on the profitable part of the mineral taken only from the measured mineral resources. (Seedorff, 2012)

iii. Stage 3 – Development

The **development** stage usually takes 4-12 years to open an ore deposit for production, and may cost \$10 to \$250 million overall. Development involves extensive pre-development

planning and paperwork. This stage may begin with purchasing a lease to mining rights to the area if not done in stage 2. A budget and financial reports are prepared and permits are requested. Reports regarding potential impacts on the environment and nearby communities are generated. Plans are assessed regarding: the technology that will be used; the building of access roads for transportation; identification of resources such as power and water sources; and construction of ore processing facilities and disposal areas for waste. At this point, \$20 million or more may have been invested in the mine, but it may fail to open if the pre-development requirements are not met, including acceptance by the community. At this stage, just enough development of the mine site is performed to ensure that it will be able to be productive for the life of the mine, without later interruption. There are two ways, stripping and excavating, to develop access to the mineral deposit, depending on where the ore is.

1. *Stripping* is used for near-surface mining, to expose mineral that is covered by a relatively thin layer of earth or rocks. It may begin as soon as the pre-development steps are complete. Stripping technique is used in copper mining.
2. *Excavating* is used for underground mining, to access to deeply-buried mineral deposits. It usually involves development of a vertical or sloped shaft, from which horizontal tunnels are created at various depths. This type of mining is usually more expensive and complex, and requires a lot of careful planning for convenience and safety.

iv. Stage 4 – Exploitation

The last stage is **exploitation**, in which the mineral is extracted or recovered from the earth in large quantities as the mine begins producing. In copper mining, stripping is the primary form of exploitation. Some exploration and development may continue at this stage, as well. This stage can take from 5-30 years to complete, and may cost five to \$50 million per year. However, many mines have been open for more than 100 years due to economic impact of price and demand. Issues of safety, technology, economics, and the environmental impact, as well as geologic and geographical characteristics of the mineral deposit itself, determine whether surface or underground methods will be used for exploitation.

v. Stage 5 – Closure/Reclamation

Local and state agencies must be contacted by mining operators when it is time to close a mine. There are different regulations that the mining operator must comply with. Before a mine is opened, a reclamation plan must be set in place for closure of the mine. There are a couple things that must be considered when planning a mine closure, and those include: long-term physical, chemical, biological and social/land-use effects on the surrounding natural systems. Four objectives must be considered when planning a closure:

- 1) Protect public health and safety,
- 2) Alleviate or eliminate environmental damage,
- 3) Achieve a productive use of the land, or a return to its original condition or an acceptable alternative, and

- 4) To the extent achievable, provide for sustainability of social and economic benefits resulting from mine development and operations.

However, these objectives can be impacted by various changing conditions. Environmental impacts of a closure plan can be grouped into four potential “impacts”:

- 1) Physical stability – physical structures must be stable to eliminate danger
- 2) Geochemical stability – metals and minerals and ‘other’ contaminants must be stable and must not migrate to places that may be harmful
- 3) Land use – pre-mining conditions must be met at the time of closure or meet compatible conditions with surrounding areas
- 4) Sustainable development – those that plan on taking over the site (succeeding custodians) should maintain the impacts of sustainability of economic and social benefit.

Assessing the possible impacts that could happen is required when closing the mine. There should also be a plan in place to address such impacts when necessary. Anticipating such measures early in the process helps to minimize potential risks and liabilities. The succeeding custodian needs to be on board early on when planning for closure to establish an agreement with the mining company on developing the closure plan to minimize risks and liabilities.

The cost of closing a mine depends on the age, location, type, and size of mine; amount of waste, geological characteristics, and type of mineral being extracted. Preliminary research shows the cost of a medium-sized open pit mine that is 10-15 years old would cost \$5-15 million to close. Compared \$50 million closure cost for an open pit mine operating more than 35 years. It is less expensive for a mining company operating the mine to close a mine than a succeeding custodian that does not know very much about the mine. Federal and state regulations require mining companies to post funding prior to mining project begins. This is to ensure that reclamation is completed at the end of the mining closure (Holt, Rinehart and Winston, 2004).

F. Processing of Copper Ores

Copper processing begins with mining and ends with the development of different types of cathodes. Figure 15 illustrates the entire copper mining processing for two types of copper ores found in the earth’s crust: sulfide ore and oxide ore. These two ores undergo two different types of processes to be made into everyday use of copper. The oxide ore has three steps before it is made into a cathode. The sulfide ore takes eight steps to reach the cathode step. When the ore is taken from the earth’s crust it is .3-1.0% copper and after it goes through further processing it becomes 99.9% copper, a cathode. After the copper is made into a cathode it is then made into wires, tubes, and plates to be used in various human usages like electronics, conducting heat, cooking utensils etc.

The first step of copper processing is mining the copper mineral. In this step, miners use blasting and various technology machinery to dig up the mineral deposits. This mining step is the sum of sequential mining steps shown in the conventional cycle of mining (Eq. 1)

including rock breakage (drilling and blasting) and materials handling (loading/excavation and hauling):

$$\text{Conventional Cycle of Mining} = \text{drill} + \text{blast} + \text{load} + \text{haul} +/\text{- hoist} \quad \text{Eq. 1}$$

To get to the copper, boring machinery is used to *drill* holes into the hard rock, while explosives are inserted into the drill holes to *blast* the rock and break it down. Sizes of minerals come in boulder size to soccer ball size. The rocks are then ready to *load* into haul trucks. Haul trucks, conveyors, trains, and shuttle cars can all be used to *haul* the ore from the blasting site to the mill. At the mill, the boulder sized minerals are crushed into smaller sizes from boulder sized rocks to golf ball size and smaller to fine sand using different types of machinery depending on ore type. There are four different types of mills that are used for grinding: rod mill, ball mill, autogenous mill, and semi-autogenous mill. After the minerals have been transported to the crusher they are inserted into a storage bin. Then the rocks are fed onto a vibrating feeder that is used to send the minerals to the jaw crusher. The jaw crusher breaks down huge rocks and is then sent to the impact crusher to be broken down to an even smaller size. The rocks are then sent to the circular vibrating screen to be screened for the various sizes of pebble sized to fine sand. In Figure 7, Zhang uses a grey square and a yellow circle to depict what is called a **gangue**. Where the yellow circle is part of the rock that is most valuable (ex: .2% copper) and the grey part of the square is considered 'worthless' (0% copper). In the copper separation step, froth flotation is used to extract copper from the 'worthless' part of the rock. Flotation is a chemical reaction that occurs to help separate the valuable parts. A chemical reagent, **surfactant**, is added which gives the mineral the ability to depend on oxygen to float.

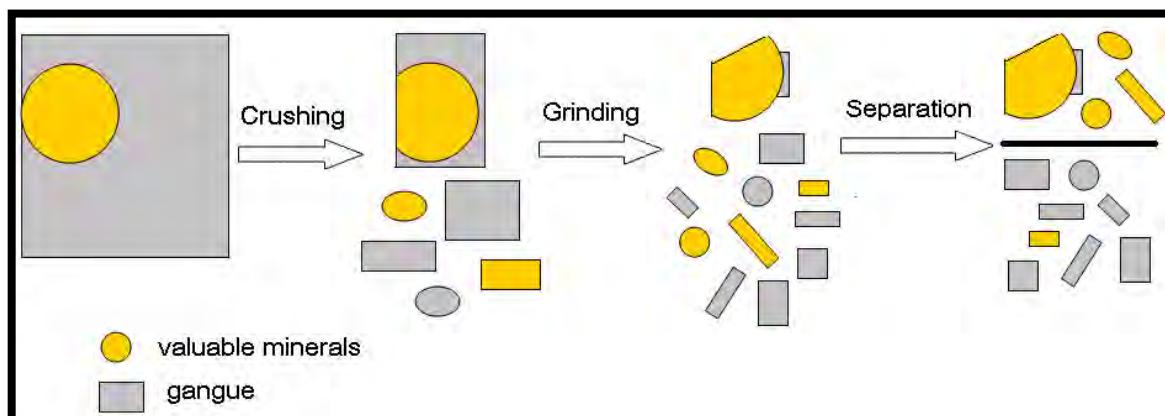


Figure 8. The process of crushing, grinding, and separation of copper once the raw materials are hauled to the copper mill.

i. Processing of Oxide Ore

Oxide ore is one form of copper mineral, and include chrysocolla and a little bit of cuprite, where some of the metallic minerals of copper have been oxidized. **Oxidation** is the loss of electrons to increase the oxidation state by way of a molecule, ion, or atom. The loss of electrons makes the ore more amendable to chemical solutions to make the mineral

dissolvable. There are three steps to process an oxide ore (2% copper) to become pure copper (99.9% copper): 1) Heap Leaching, 2) Solution/Extraction, and 3) Electrowinning. **Heap Leaching** is the process of using percolating solutions to leach out the metals in a crushed heap pile. The heap pile is located on a base that has a 3° slope to help collect the leachate, or metals washed down by solution (Figure 8).

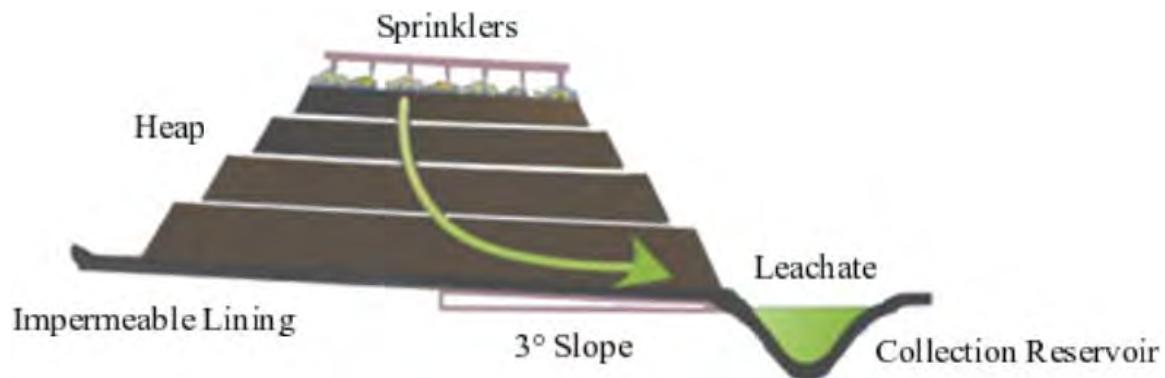


Figure 9. This figure illustrates the process of heap leaching. Acid sprinkles on top of the heap to bind to metals and flows down the slopes to be collected in a collection pond called Leachate.

The leaching reagent is sent through sprinklers on top of the heap pile and flows down through the heap to help collect metals. At the bottom of the base the liquid made of reagent solution and extracted metals is collected in a small pool. The second step is solvent extraction, where the reagent solution with metals is separated based on solubility to create two different liquids.

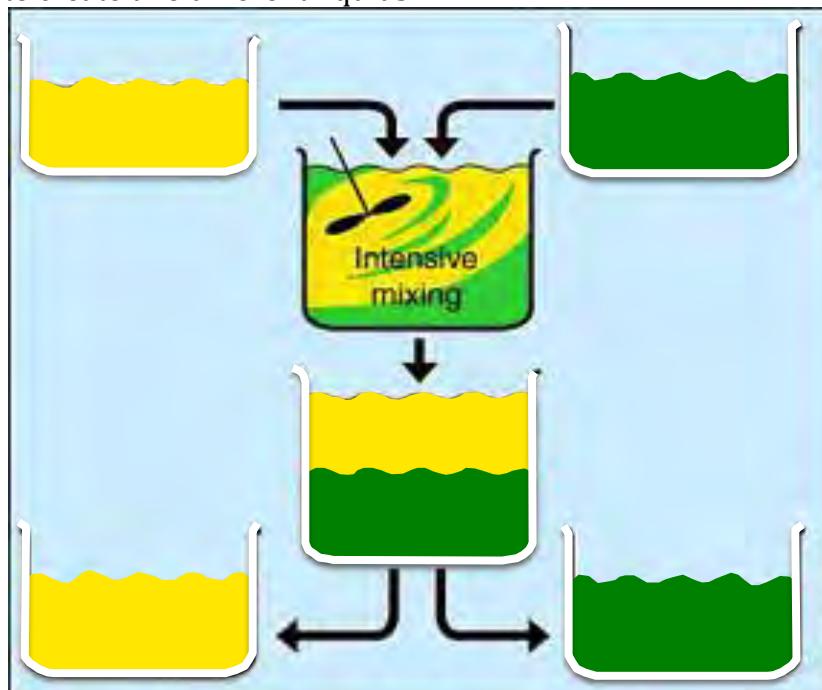


Figure 10. This figure illustrates the process of solvent extraction.

This reaction creates a water-oil mixture. The metals are extracted from the solution and the reagent solution is recycled to be sent through the sprinklers again. The last step is called electrowinning, meaning electrical current is used to plate copper metal onto a cathode.

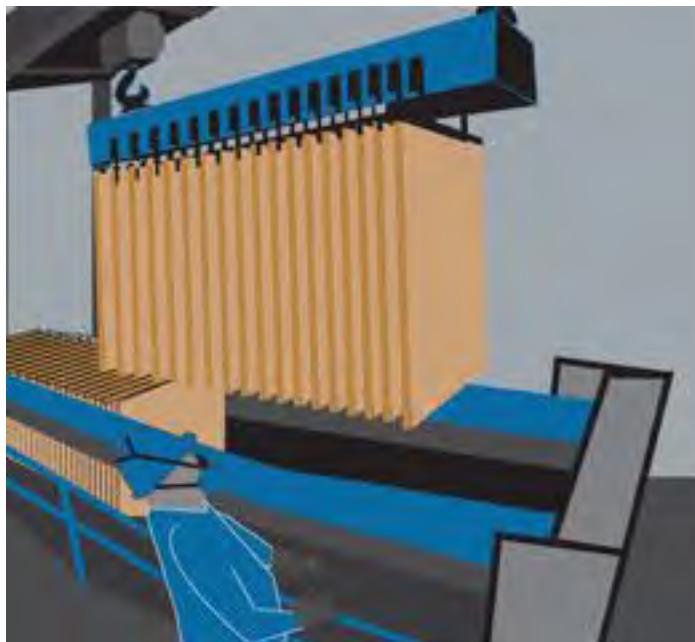


Figure 11. This figure illustrates the process of electrowinning.

Current is passed through an anode and cathode to cause charged metal particles to move making impure copper to pure copper.

ii. Processing of Sulfide Ore

Sulfide ore is the second form of copper mineral and include chalcocite and chalcopyrite which are found in various mines in southern Arizona. After the minerals are mined and hauled to the mill, the ores are crushed. A gyratory crusher is used to reduce the size of the rock to approximately 6 in diameter. The rocks are then reduced to a smaller size by another grinder called a mill grinding. Steel balls or long rods are used to crush the small pieces to fine sand, while water is added to make slurry. Chemical reagents are added to the slurry after it leaves the mill grinder to be sent to floatation.

Froth floatation is where the slurry reacts with two reagents, a “frothing agent” and a “collector.”

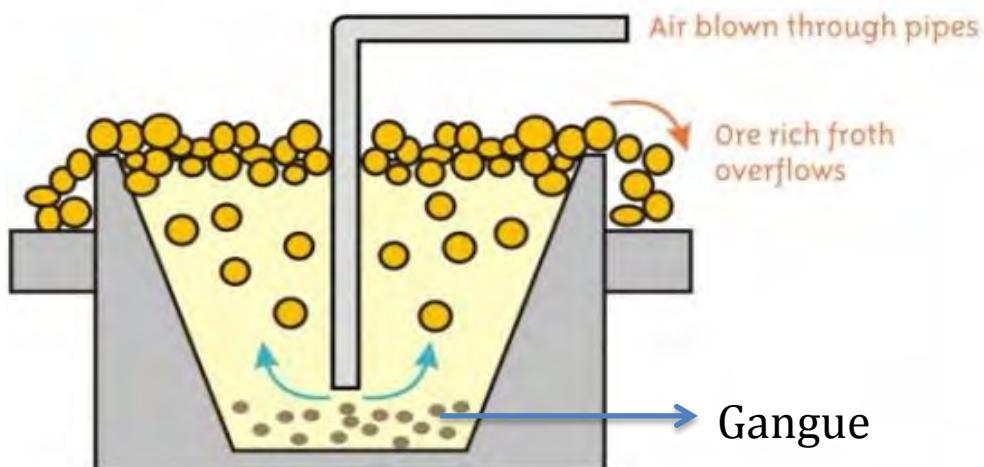


Figure 12. This figure illustrates the process of froth floatation.

The slurry is a mixture of waste rock, ore and water which is also known as pulp. The pulp is mixed with a chemical solution called “frothing agent” inside a tank. Pipes are used to blow air into the bottom of the tank to create frothing bubbles. The second reagent called a “collector” (potassium xanthate) acts a waterproofing agent. It makes the ore mineral waterproof so that it can cling to the bubbles to rise to the surface. The waste rock from the slurry does not become waterproof because it cannot react with the “collector” agent. So the waste rock then sinks to the bottom of the tank to be removed or disposed of. Froth floatation helps separate the waste rock from the sulfide mineral.

The next stage after froth floatation is the thickening stage where the concentration of copper increases with each step. The froth is poured into a large tank called thickeners. While the froth is being sent to the thickeners the bubbles have broken. The solids inside the froth solution settle at the bottom of the tank are called copper concentrate that is raked to be filtered. Filters remove the water from the copper concentrate before it is sent to the smelter. The water is recycled back into the mill to be reused in the process. After the water is removed the mixture is a combination of other metals and copper concentrate that contains 30% copper that is sent to the smelter. The smelter decomposes the ore by using heat and a reducing agent to drive off other elements like gas and slag, leaving behind only metals.

There are four smelting processes that copper goes through to be processed: 1) smelting furnace, 2) converter, 3) refining furnace, and 4) anode casting wheel.

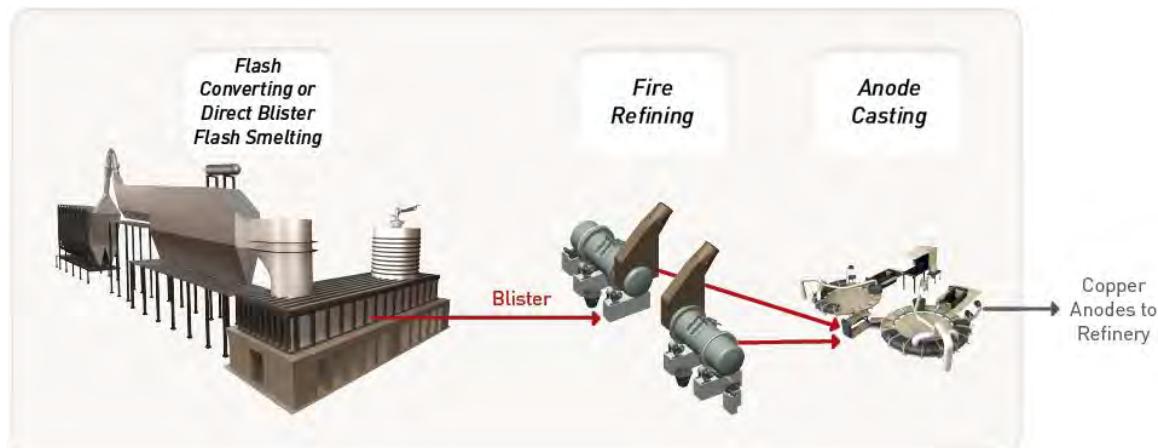


Figure 13. This figure illustrates the four processes that copper undergoes to be refined.

The copper concentrate is first sent through the smelting furnace. This is where ground-up rock is heated up to 2,300 °F to be converted to molten liquid. The heated liquid is poured into a slag settling furnace. This step produces a combination of matte and slag together where matte is a mixture of copper, sulfur and iron and slag is a dense, glassy material made of mostly iron and silica. The matte created by the smelting furnace contains 58-60% copper. Matte is made of mostly copper and iron while slag is made of iron, silica, and other impurities. The molten matte is then taken to another furnace called a converter to have the remaining iron and sulfur burned off. After the two elements, iron and sulfur, have been burned off the matte is then referred to as blister copper. At this stage, blister copper contains 98% copper and is then taken to the anode furnace to be refined. Air is blown into the mixture to burn off the oxygen. The blister copper has a yellow color to it but when the oxygen in the copper is burned off it turns a blue-green color. At this point, the molten metal is now called anode copper. The anode copper is poured into a heated trough while natural gas flames are blown on the top to prevent oxygen from being absorbed into the metal. The anode copper is poured into two scales to be measured and shaped into molds to be casted in anode casting wheels. One mold holds between 750 and 850 lbs of copper with 16 molds per wheel. One rotation of the wheel is completed every 15 minutes to produce more than 120 anodes every hour. Before the red-hot anode is taken out of the mold, it is quickly cooled down in minutes with water spray. The finished castings contain 98 to 99% copper and are now called anodes. Anodes have a thickness of 2 inches per slab of copper, have a width of 3 feet wide, a height of 3 feet, with two handles molded on top. The end product contains 99.0% pure copper and is taken to a refinery to become 99.9% copper.



Figure 14. Copper anode slab after it is taken from a furnace to be molded in to 2 inch thickness, 3 feet wide, a height of 3.5 feet, 750 lbs in weight and is 99% pure copper.

The refining process uses electrical current to pass through a solution from an electrode to another electrode, called electrolysis.

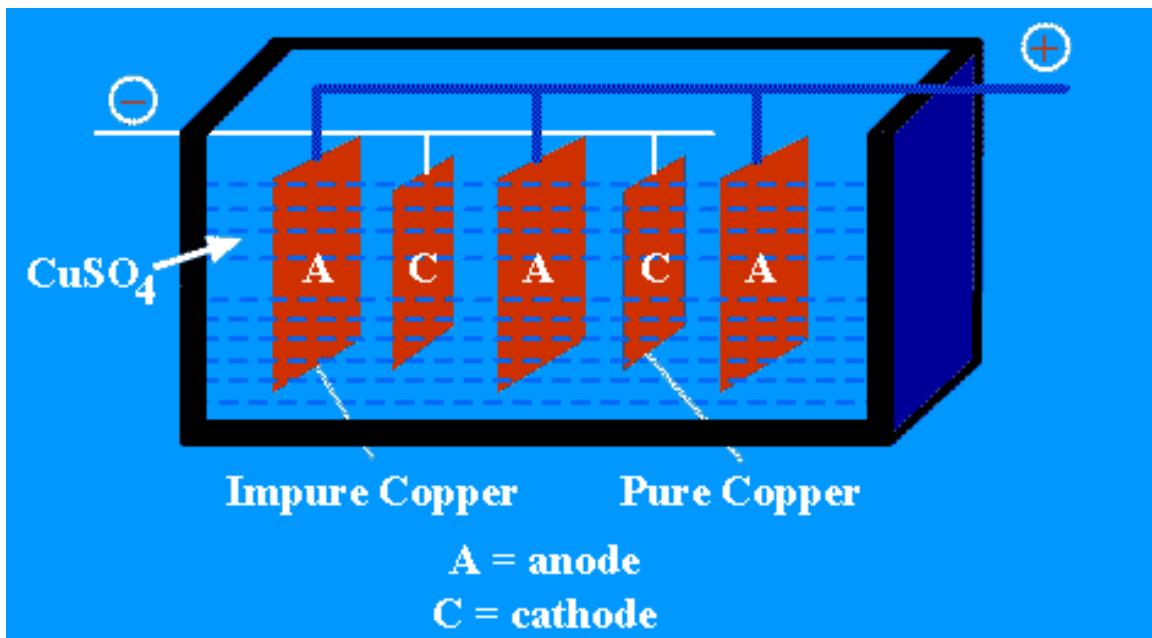


Figure 15. This figure illustrates the electrolysis process of a anode (impure copper and the cathode (pure copper).

The anodes are hung in a large tank full of a solution called electrolyte, made of copper sulfate and sulfuric acid. Thin sheets of pure copper act as cathodes are hung in between the anodes. The cathodes weigh about 15 lbs each when an electrical current passes through the anodes and through the electrolyte solution to the cathode. The copper from the anodes moves into the solution and is plated onto the cathode sheets. It takes about 14 days for the cathode to accumulate copper from the anodes. The sheets weigh about 375 lbs after 14 days and are taken out of the tank and rinsed with water to stop the chemical reaction. Copper and other metals such as impurities also leave the anode to drop to the bottom of the tank or stay in the electrolytic solution. These impurities are collected and are refined to recover other metals such as silver and gold. The copper cathode is melted again to undergo another process to be made into wires, plates, and tubes for human usage.

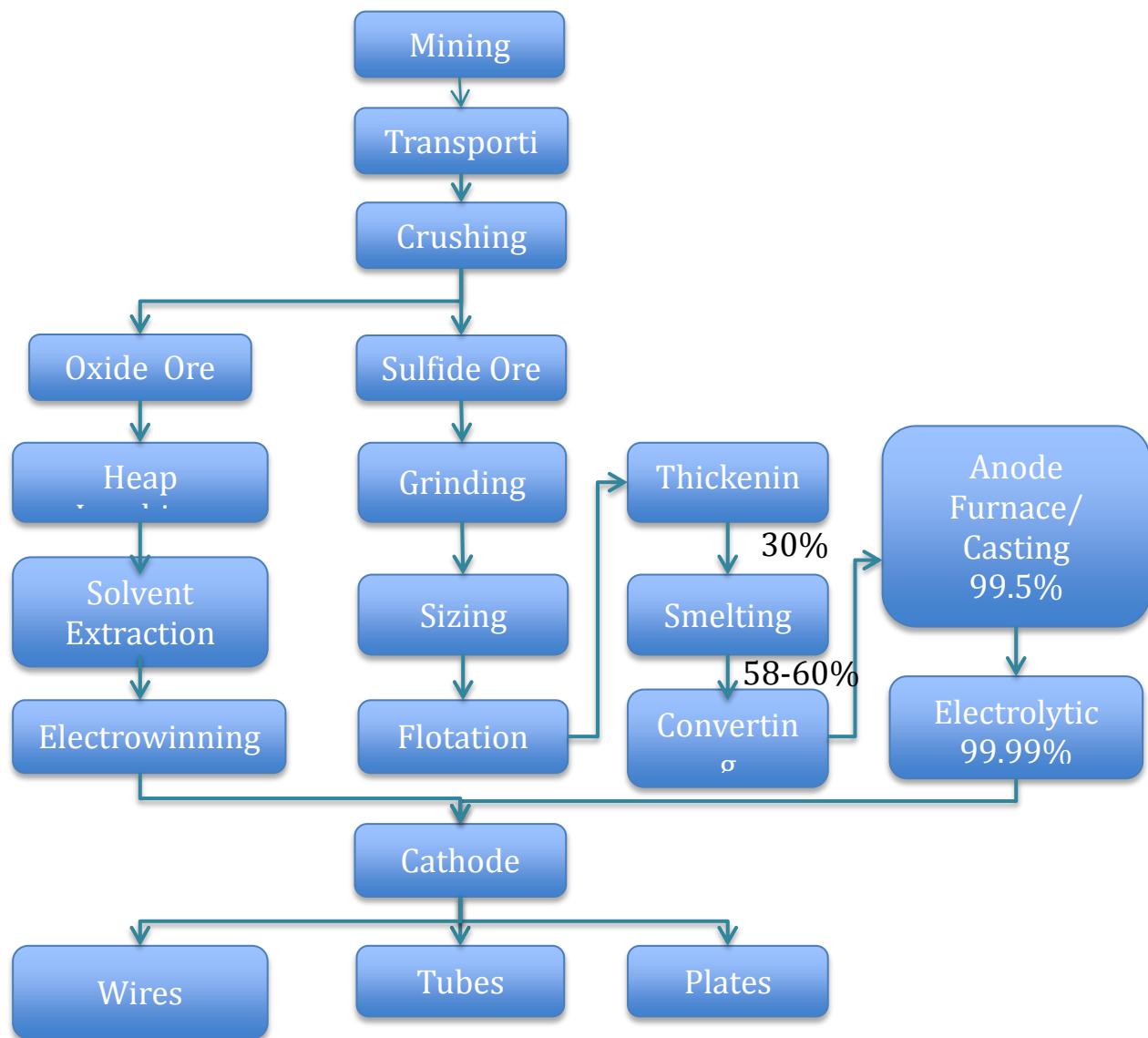


Figure 16. Shows the process of what Copper goes through from mining to everyday usage.
 Source adapted from http://www.sinocop.hk/html_eng/projects/why copper/process.html

Sustainable uses of Copper

Brundtland Commission gives a definition of **sustainable development** as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” Meeting the needs of future generations can be done by recycling raw materials that are being used presently. Copper is a form of raw material found in the earth’s crust that can be continuously recycled without losing its properties. Recycling is a form of practicing ‘going green’ to be more environmentally friendly. There are three areas that copper can contribute to sustainable development: environmental protection, economic growth, and social considerations.

Recycling copper helps conserve for future generations by reducing landfill costs because it is too valuable to be discarded. When copper is mined and processed, it burns off gases like CO₂ that are emitted and collected to protect the environment. Recycling copper helps to conserve fossil fuels and reduces toxic gases that could be released into the environment. Copper is highly useful for technological advances to enhance performance in machinery for microprocessors and other small-scale machinery. When copper is recycled it is impossible to notice a difference between new and recycled copper. To recycle copper the metal is melted and re-purified and can be manufactured into new components or reused in smelting operations (Scott, 2011). Both are used to make long lasting products which in return provides economic benefit. In 2010, 770,000 metric tons of copper was recycled which is equivalent to \$5,940,000 dollars (Papp, 2010).

As mentioned at the beginning of this report copper is known for its antibacterial properties in controlling transmission of foodborne and pathogens like E.coli O157 and many other bacteria. It also limits water-borne pathogens by traveling through copper pipes and vessels to deliver clean water. One cm² of copper can eradicate 10 million germs in 1 hour and 30 minutes. Copper is vital to plants and animals for normal growth providing essential micro-nutrient for living tissues.

Copper is used in constructing homes and buildings because it resists corrosion, its durable, and doesn’t need maintenance. Copper is used in various ‘green’ products like the hybrid car. Copper is used in various renewable energy products, antibacterial products, development, nutrition, and energy efficiency.

Educational Opportunities

There are a variety of opportunities to pursue a career related to mining. Some majors at the University of Arizona are (but not limited to) mining engineering, metallurgical engineering, civil engineering, chemical engineering, material science engineering, mathematics, geology, geographic information systems, geophysics, hydrology, geosciences, environmental science, public health, and chemistry. The majors listed above can lead to a job in Mining Operations, Geomechanics, Sustainable Resource Development, and Mineral Processing (these are the tracks in mining engineering).

Conclusion

Copper mining contains both positive and negative impacts on the environment and among people. In the information provided above, we have provided the process in which copper is mined to provide basic information of what is known in the southeastern part of Arizona. Mining impacts tribal nations in various aspects. This report is to provide information for tribes regarding copper mining, copper processing, and environmental impacts, and mining precautions. Having a good knowledge foundation of what is in their local area can help a tribal member be aware of their surroundings to protect their land and way of life. Copper is used in every day household products but has to be mined before it can be used in the home.

Comprehensive PowerPoint Lecture

Copper Mining

Jennifer Stanley, Research Assistant
Karletta Chief, Assistant Professor & Extension Specialist

Superfund Research Program

- Theme
 - "Hazardous Waste Risk and Remediation in the Southwest"
- Goals
 - Address the health effects of contaminants of concern in the U.S. Southwest (and Mexico border)
 - Characterize, contain, and remediate hazardous waste sites
- Emphasized hazards
 - Arsenic
 - Chlorinated solvents
 - Mine tailings

Educational Modules

- Partnership between UA Superfund Research Program and Tribal Colleges
- Develop mining and environmental educational modules for tribal colleges to enhance the understanding of
 - Copper mining and processes
 - Environmental impacts of mining
 - Remediation techniques
 - Mining exposure and risk
 - Mining mineral economics

Objectives

- Understand basic information about copper, occurrence, and use
- Learn history and current status of copper mining in the United States, Arizona, and Tohono O'odham tribal land
- Understand five stages of copper mining including prospecting, development, exploration, exploitation, and closure/reclamation
- Understand different types of copper processing for oxide and sulfide ores

Copper is an Element

Copper
29
Cu
63.54

- Solid metal
- Bright metallic luster and is reddish orange
- Found as native (pure) copper or combined with other elements



How is Copper used?

- Common copper alloys (mixtures of elements) are bronze and brass
- Currency
- Cooking pots
- Wiring/Electronics
- Jewelry
- Clothing
- Anti-bacterial products



Major Uses

Type of Market	% Copper Consumption	Copper Consumption [million lbs]	Examples
Construction	50.6%	3,946	Wiring and plumbing
Electronics	19.3%	1,500	anything with an on/off switch
General Consumer Products	10.7%	829	Household appliances, etc.
Transportation Equipment	10.5%	814	Cars, trucks, trains, etc.
Industrial Equipment	8.9%	691	Power plants and transmission lines?

Copper Minerals



- Found as
 - Copper sulfides (chalcopyrite and chalcocite)
 - Copper carbonates (azurite and malachite)
 - Copper silicates (chrysocolla)
 - Copper oxides (cuprite)
 - Native copper



History

- Discovered: early 9000 BC in Middle East
- Prehistoric uses
 - Utensils, tools, weapons, piping, ornaments and jewelry.
- Smelting was discovered in different parts of the world
- 3500-2500 BC Chalcolithic period
 - Rise in the use of copper
 - Discovery of bronze

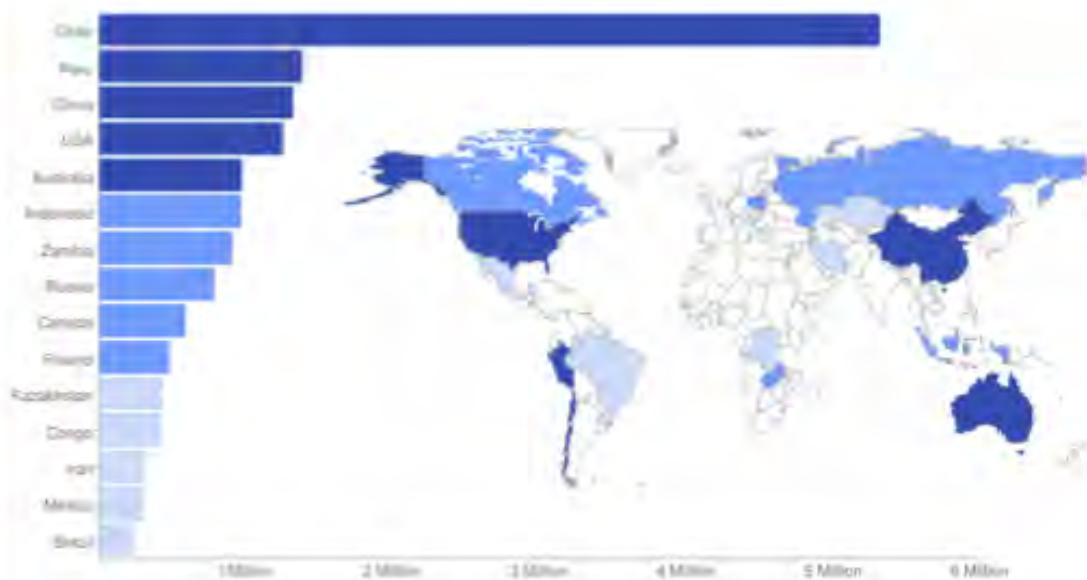
History cont.

- 250 BC
 - Roman used Copper as currency
 - Brass coins
- 23 BC
 - Copper coins

History

- 5000 BC – 1200 BC
 - Largest deposit of copper found in Michigan
 - Keweenaw mines
 - Native Americans mined copper
 - Evidence: knives, arrows, spear heads, and axes
 - Not mined on a commercial scale

Copper Mine Production by Country - Top 15, 2010 (Tonnes)

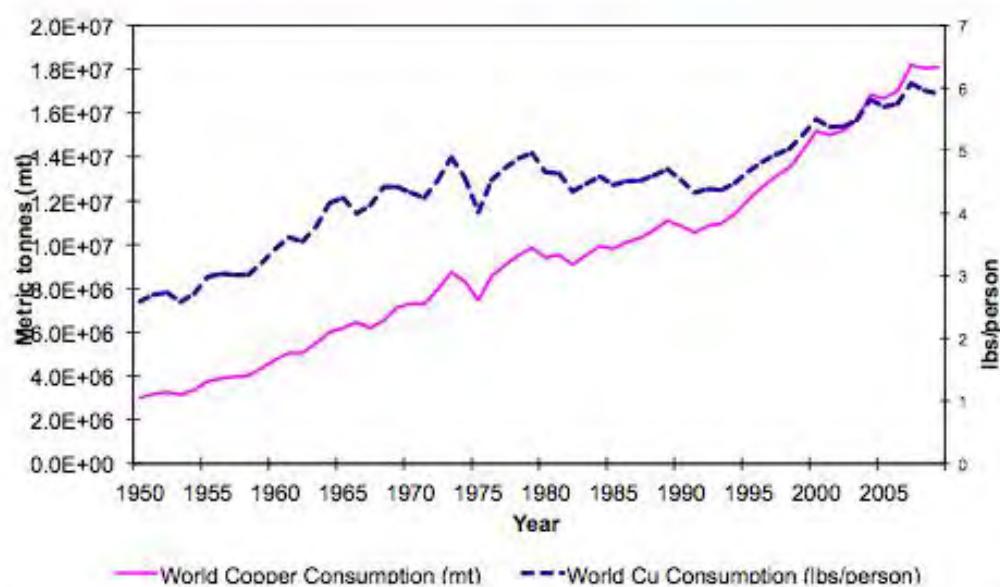


Copper Deposits by Country



From Kessler, 1994, "Mineral Resources, Economics, and the Environment",
MacMillan, New York.

World Consumption of Copper



Hammond, David 2012 Presentation - Mineral Economics: The Issue of Resource Scarcity, University of Arizona

Impact on Cu Price

Over the last 100 years, the real price and cost of copper has halved
Copper price and (estimated) average operating costs for Western World: 1900-2009



USGS, Brook Hunt, CRU, MinEx Consulting estimates (for 1900-2009.)

MinEx Consulting

Strategic advice on mineral economics & exploration

3.1

15

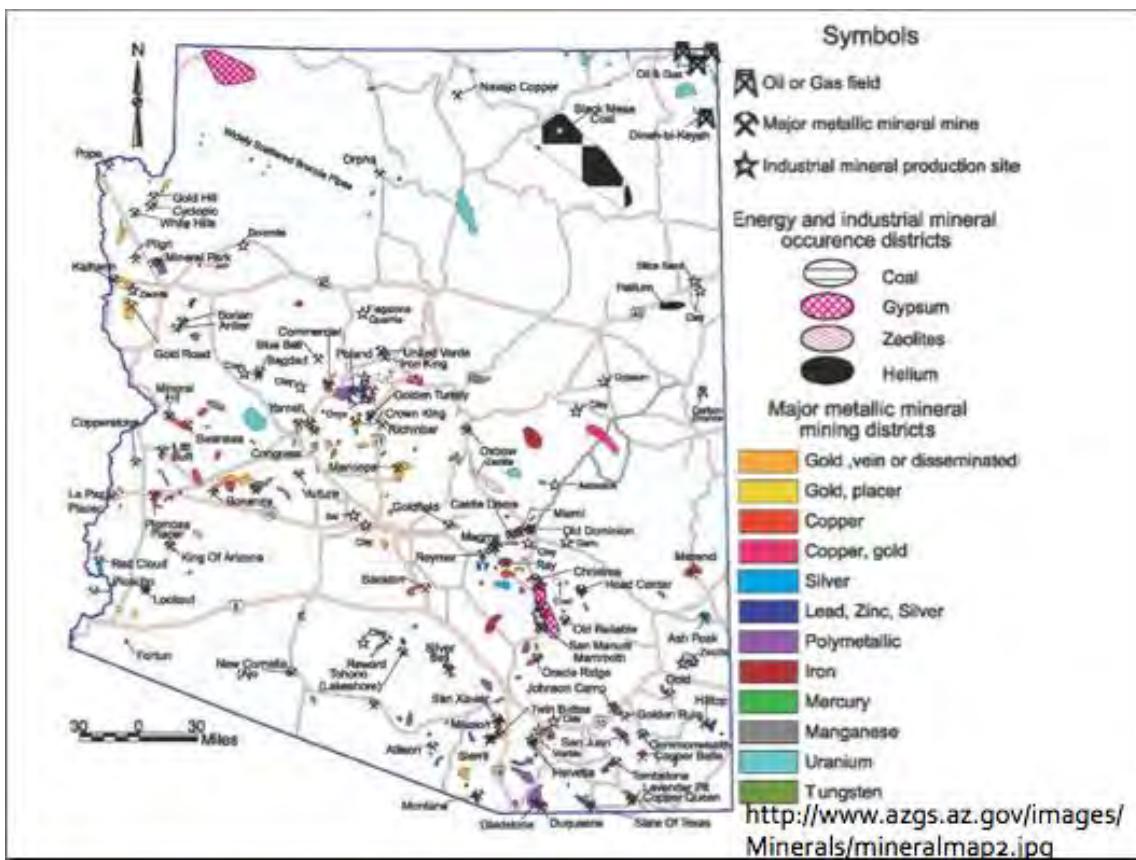
Mining in Arizona

The 5 C's

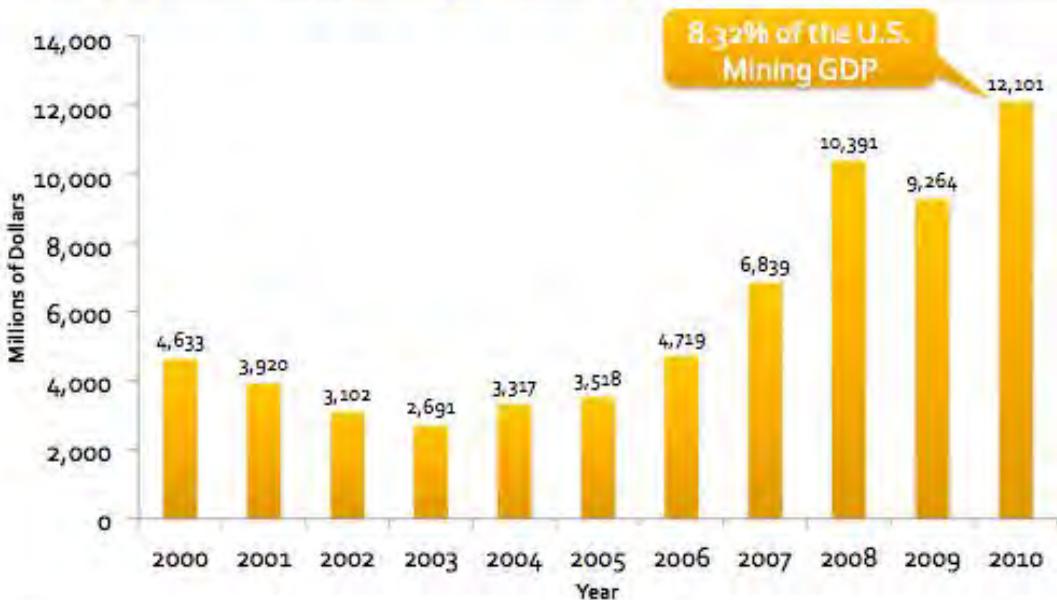
- Cattle
- Citrus
- Climate
- Copper
- Cotton



Morenci Mine
#1 in the U.S
#9 Worldwide



Direct and Indirect Impact of Copper Industry in AZ, 2000-10



Arizona Copper Production (2010)

- Arizona produced 63% of U.S. copper
- Copper mining industry in Arizona
 - \$12.1 billion / 4.63% of AZ economy
 - 73,100 jobs
- Average price of refined copper
 - \$2.37/lb (2009)
 - \$3.43/lb (2010)

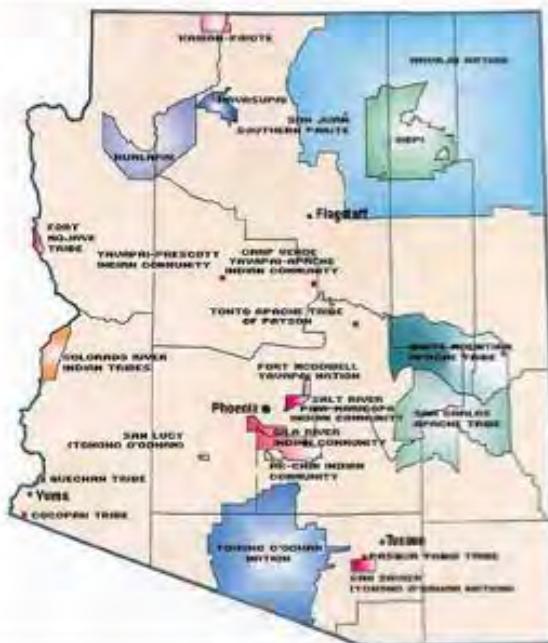
<http://azgeology.azgs.az.gov/article/minerals-and-mining/2011/09/2010-arizona-mining-review>

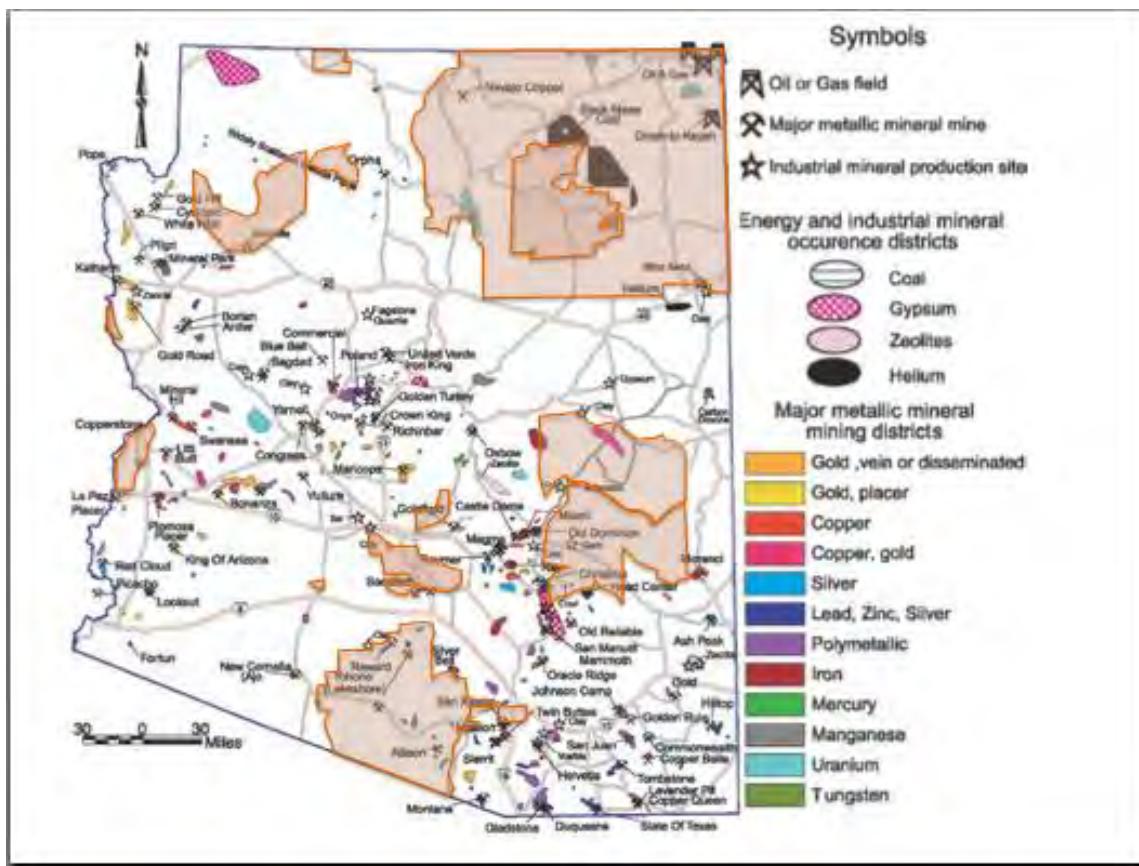
Mining on Tribal Lands

Tribes' Legal Voice in Mining

- 1938 Indian Mineral Leasing Act
 - Supported tribal gov'ts, promoted tribal development
- 1978 American Indian Religious Freedom Act
 - Protection of sacred sites
- 1982 Indian Mineral Development Act
 - Allowed negotiated agreements subject to Secretarial approval (tribes have to go to court)

Arizona Reservations





Mining near & on Tohono O'odham land



Mission Mine

- Current pit
 - 2.5 miles long
 - 1.5 mile wide
 - 1,200 feet deep
 - situated on 20,000 acres.
- Located on the south end of San Xavier District



Cyprus Tohono Mine

- Inactive
- Sulfide minerals
- Reclamation work in 2007
 - Evaporation ponds
 - Old tailings impoundments
 - Area protected by plastic liner



Rosemont Mine

- Augusta Resource Corporation
- Copper/Molybdenum Reserve
 - Cu: 5.9 billion lbs
 - Mo: 194 million lbs
- Feasibility study
 - Production of ~243 million lbs of copper annually
 - \$1.02/lb of copper



Rosemont Mine



- Nearing last stages of permitting
- Production to start in 2015
- Looking to be the 4th largest copper mine in the United States

5 Stages of Mining

Stage 1 - Prospecting

- Usually takes 2-8 years
- Research existing information
 - Location: communities, surroundings
 - Old maps & mines in the area
- Geologic mapping
 - Air: aerial photography
 - Space: satellite imagery
 - Surface: geology
- Measure rock properties
 - Geophysics: measure physical properties of rocks
 - Geochemistry: measure chemical dispersion from weathering
 - Drilling: record position and type of rocks at depth
- Information may or may not lead to a discovery of valuable minerals



U.S. Geological Survey, Mineral Resources Program, 2009, Mineral Resource Assessment of the Yukon, Canada

Stage 2 - Exploration

- Usually takes 2-5 years
- Purchase lease adhering to Mining Rights
- Determine size and value of the mineral deposit
- Drill for more information
 - Core Samples (richness and extent of minerals)
- Evaluate the samples
 - Is it valuable?
 - How much will it cost?
 - What are the risks?
- Produce a feasibility report: "go – no go" decision
- Bottom line: Is the mineral deposit an ore deposit



Image source: www.mindat.org/photodb/100000/100000.html

Minerals vs Rock

Mineral – naturally occurring homogeneous solid with definite (but generally not fixed) chemical composition and an ordered atomic arrangement. It is usually formed by inorganic processes



Rock – a naturally formed, stable aggregation of minerals



Calcite is a mineral, limestone is a rock containing calcite

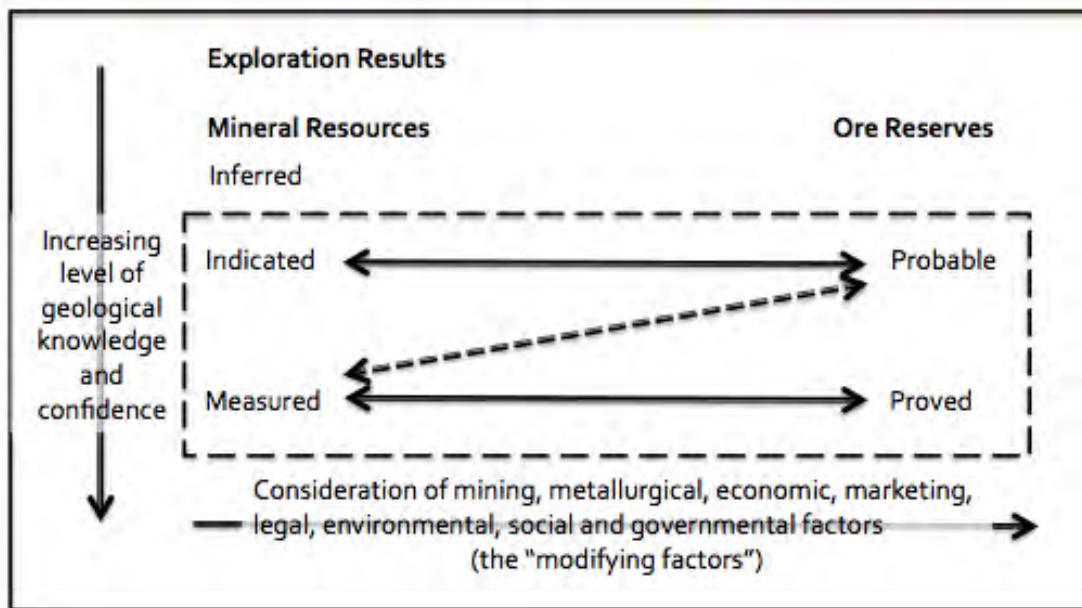
Mineral Deposit vs Ore Deposit

Mineral occurrence – anomalous concentration of minerals

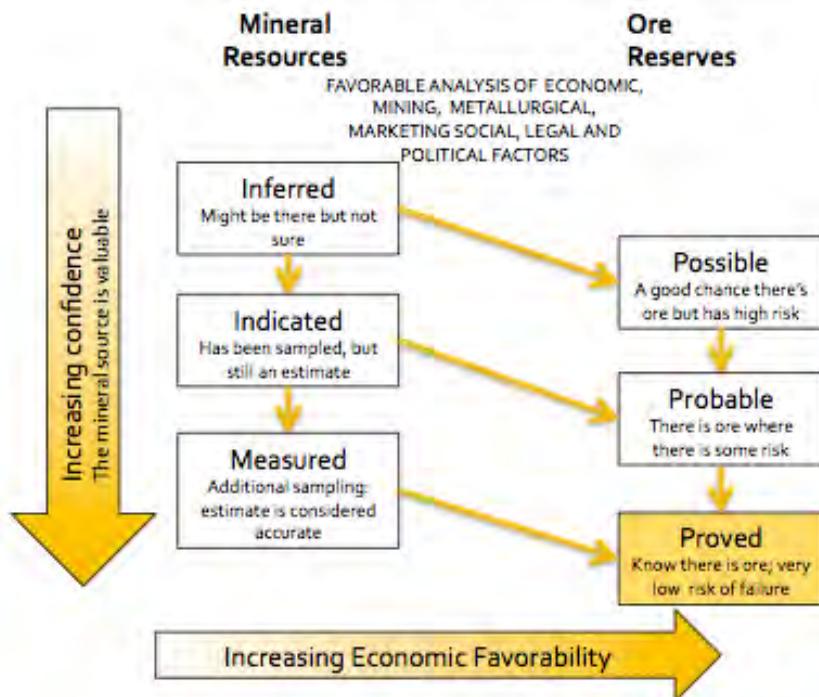
Mineral deposit – concentration is great enough to be of potential economic importance

Ore deposit – minerals can be extracted and processed at a profit

Relationship between Exploration Results, Mineral Resources and Mineral Reserves



Conceptual Relationship of Resources and Reserves



Source: Adapted from Grimley (1987)

Stage 3 - Development

- Usually takes 4-12 years
- Prepare budget and arrange financing
- File a report of impact
 - Environment, community, safety, etc.
- Assess what is needed
 - Permits, technology, roads, disposal sites, etc.
- Construct facilities and excavate deposits
- Millions of dollars invested by this point

Stage 4 - Exploitation

- Usually lasts 5-30 years
 - (many mines are now 100+ years – very dependent on commodity type)
- Remove ore
 - Conventional cycle = drill + blast + load + haul
- Maintain safety at all times

Stage 5 – Closure

- Usually lasts 10-35 years
- Four objectives must be considered when planning a closure:
 - Protect public health and safety
 - Alleviate or eliminate environmental damage
 - Achieve a productive use of the land, or a return to its original condition or an acceptable alternative, and
 - To the extent achievable, provide for sustainability of social and economic benefits resulting from mine development and operations
- Depends on age, location, type, and size of the mine and other factors

Copper Mining Process

Cu Process



Mining

- The process, industry, and occupation of extracting minerals from the earth's crust (Hartman, 1992)



http://www.dreamomania.com/dreamdictionary/actions/mining_meaning/

Transporting

- Haul trucks are used to transfer minerals to the mill from the excavation site



<http://curezone.com/ig/i.asp?i=12831>

Crushing

- Minerals are broken down from boulder size to golf ball size and smaller

Jaw Crusher



Ball Mill



<http://mining.crushersmill.com/production-line/copper-ore-grinding.html>

Crushed

Oxide
Ore

Sulfide
Ore



Cuprite



Chrysocolla



Chalcopyrite



Chalcocite

Oxide Ore

(Cyprus Mine)



Oxide Ore

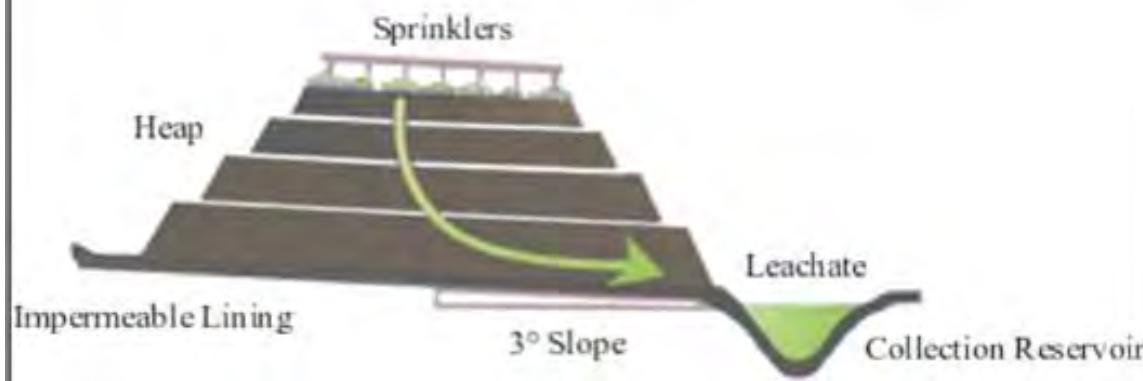
Cuprite
 Cu_2O

- When in contact with oxygen in the air, it forms copper oxide.
- Mineralized rock in which some of the original minerals have been oxidized
- Chemistry
 - Oxidation – the loss of electrons is an increase in oxidation state by a molecule, ion, or atom
- Oxidation tends to make the ore more amenable to chemical solutions so the mineral can be dissolved



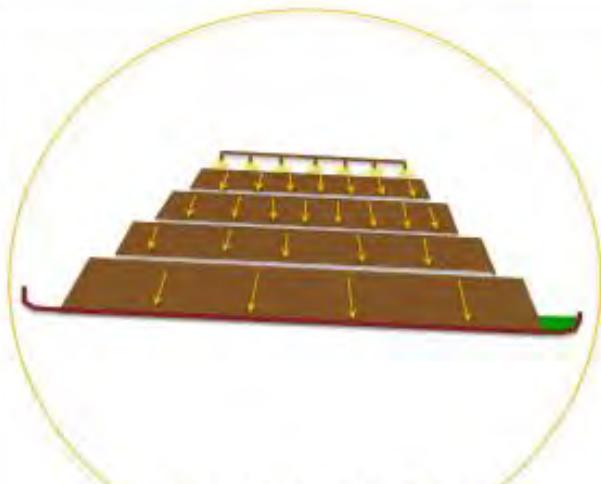
Heap Leaching

- Process in which metals are leached from a pile of crushed ore by a percolating solution



<http://www.wealthdaily.com/articles/copper-mining-company/2059>

Heap Leaching



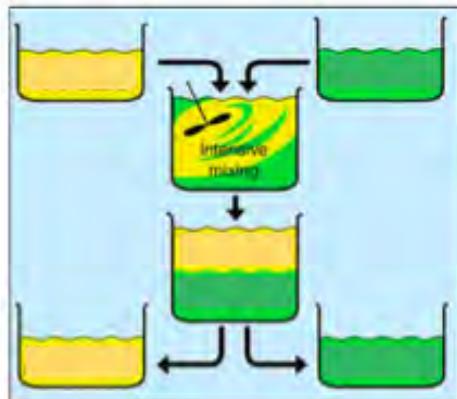
Leaching reagents (yellow) will solubilize metal from the ore to extract the copper (green)



Leaching reagents (yellow) will solubilize metal from the ore to extract the copper (green)

Solvent Extraction

- Separating compounds based on solubility into two different immiscible liquids
 - Water
 - Organic solvent



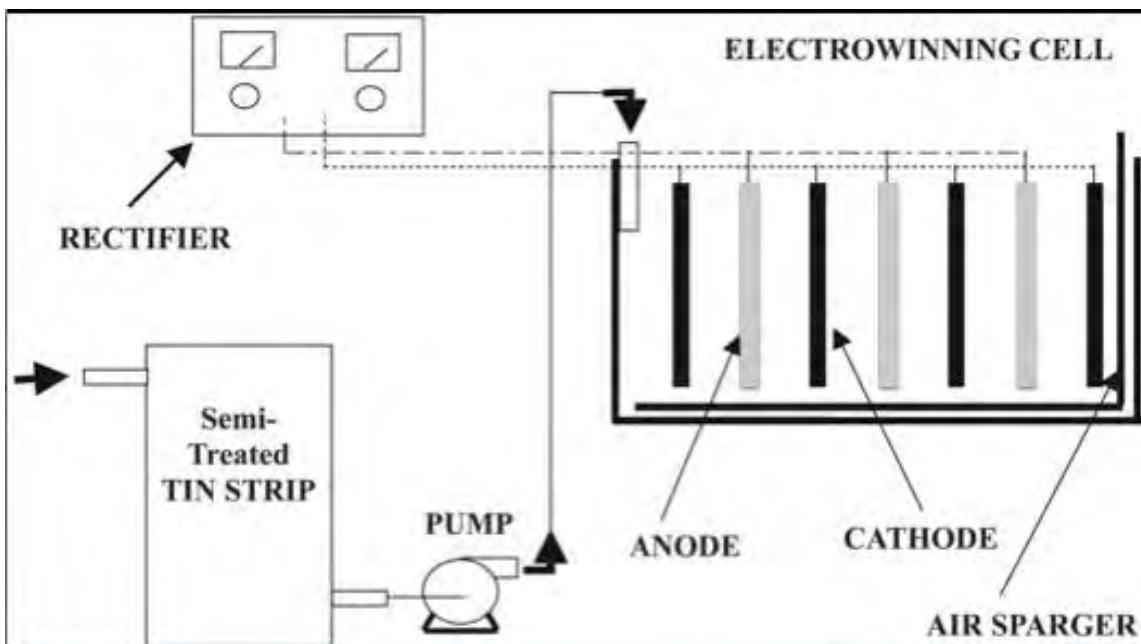
Source: http://en.wikipedia.org/wiki/Solvent_extraction

Electrowinning

- Plating metal onto a cathode (plate) using a current



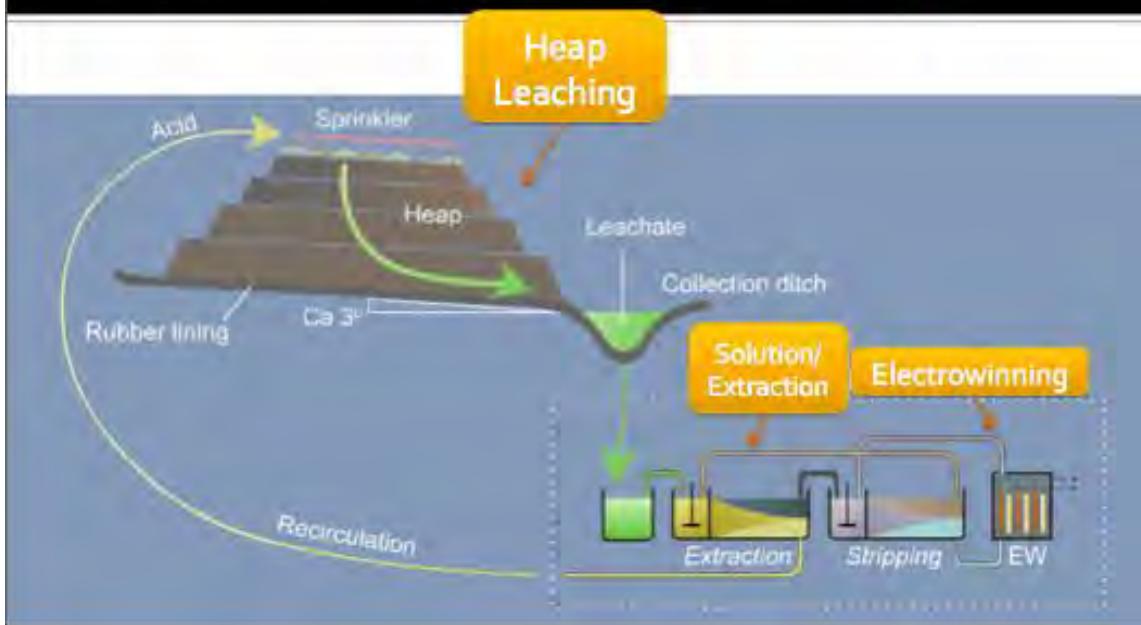
Source: http://ar07.angloamerican.solutions.investis.com/ofr/business_unit/base_metal/strategy_dev.htm



- Copper can be recovered by introducing a direct current between an anode (positive charge) and a cathode (negative charge)
- Electrical current causes charged metal particles to move

Source: <http://www.emeraldinsight.com/journals.htm?articleid=878357&show=html>

Oxide Ore Process Summary



Sulfide Ore

(Mission Mine)

Sulfide Ore



Chalcocite
 Cu_2S



Chalcopyrite
 $CuFe^{2+}S_2$

- A sulfide is an anion of sulfur in its lowest oxidation number of -2
- Sulfide ores are an important source for production of Cu
- They contain not only sulfides but also other minerals that make it complicated to extract metal of interest
-

Source: <http://encyclopedia2.thefreedictionary.com/Sulfide+Ore>



Grinding

- Ore is ground into fine particles using steel balls, long rods or sometimes just ore and water
- Makes a slurry
- Reagents are added and slurry is sent to floatation

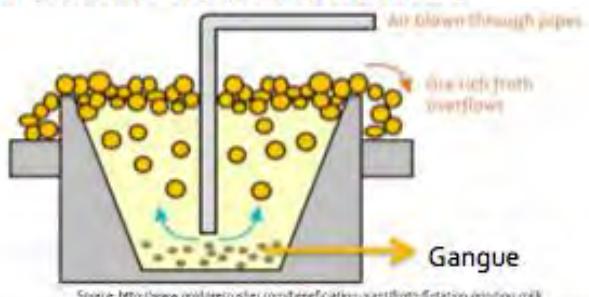


Froth Flotation

- Copper is chemically attracted to a frothing agent
- Strong bubbles are created by blowing air into the solution. The “frother” helps make the bubbles a certain size and strength
- A “collector” adheres to the copper minerals and allows the minerals to stick to the bubbles



Source: <http://strayspintchile.blogspot.com/2008/10/as-hortolas-plant-for-los-broncos-mine.html>

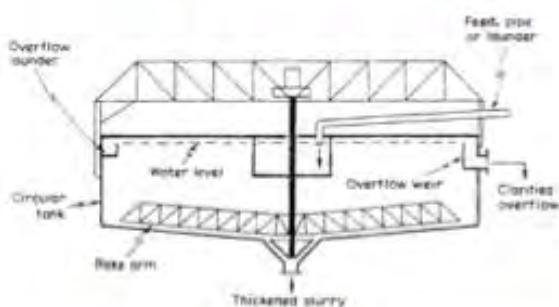


Source: <http://www.goldminesuisse.com/beneficiation/plant/froth-flotation-grinding-mill>



Thickeners

- Froth containing chalcopyrite flows into the center of large tanks called thickeners
- Solids settle at the bottom and water is recovered and re-used



Increasing Copper Concentration



Copper Concentrate



- Copper concentrate sinks to bottom of thickeners and pumped to filters
- Filters remove water to prepare copper concentrate for transport to smelter
- *Removed water is recycled back into mill to be reused*
- Result is a mixture of copper and other metals (~30% copper)

Smelting



Source: <http://www.abb.com/cawp/seitp202/1a19293a6ee21f30c1257a3e0033a86f.aspx>

- Smelting uses heat and a reducing agent to decompose ore
- Driving off other elements as gases or slag
- Leaving metal behind

Four Smelting Processes



- Smelting furnace
- Converter
- Refining furnace
- Anode casting wheel

Smelting furnace

- Concentrate is smelted
 - Concentrate is converted to molten liquid (2,300°F)
- Molten liquid is poured in controlled way (tapped) into slag settling furnace
 - Produces combination of matte + slag
 - Matte-mixture of copper, sulfur and iron
 - Slag-dense, glassy material of mostly iron and silica
- Matte contains 58-60% copper

Converter

- Matte flows into ladle to be picked up by a crane and poured into converter
- Remaining iron and sulfur is removed by blowing air into mixture to burn them off
- Results in Blister Copper
 - 98% copper



Anode furnace



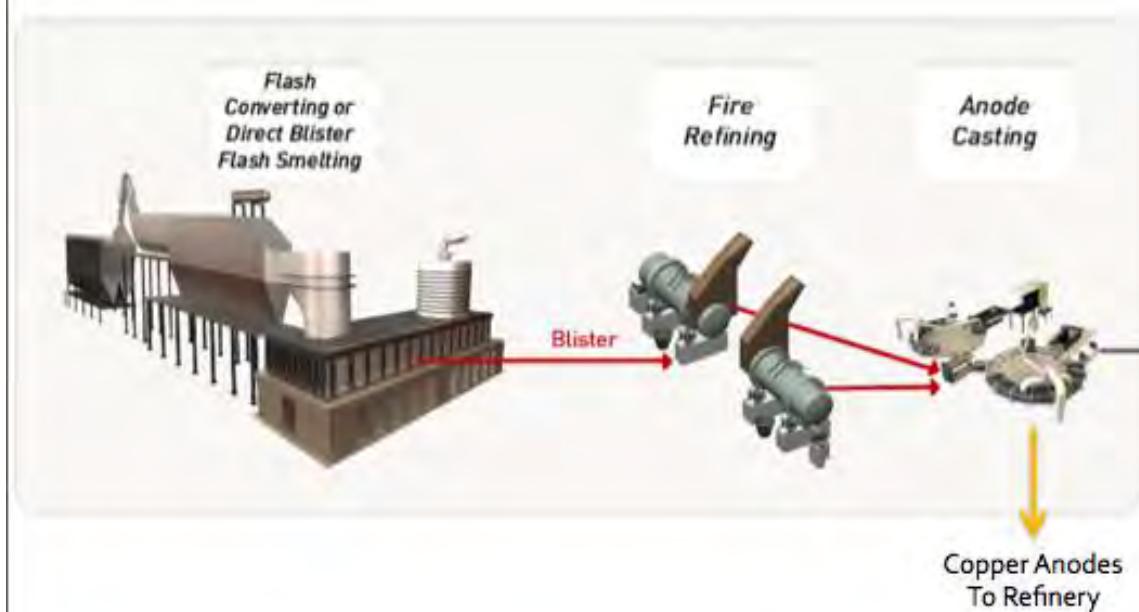
- Blister copper is poured into anode furnace where additional refining is performed
- Air and natural gas are added to the mixture to burn off the Oxygen

Anode casting wheel

- Copper from anode furnace is poured into copper molds to produce anodes
- Anodes: slabs of copper
 - 2 in thick
 - 3 ft wide
 - 3.5 ft tall
 - 750 lbs
 - 99.0% Pure Copper



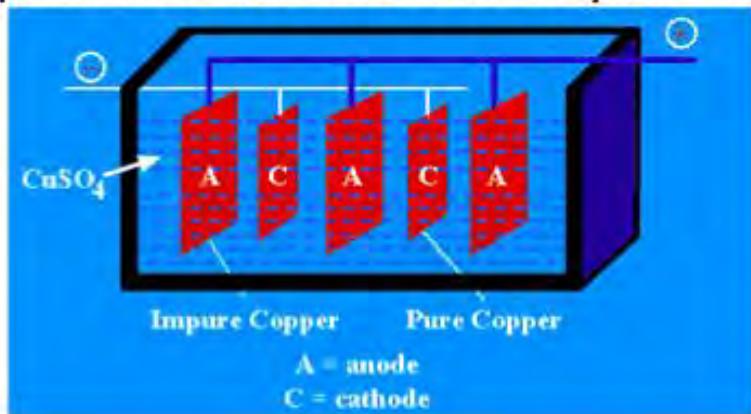
<http://www.xstrata.com/annualreport/2006/page69>



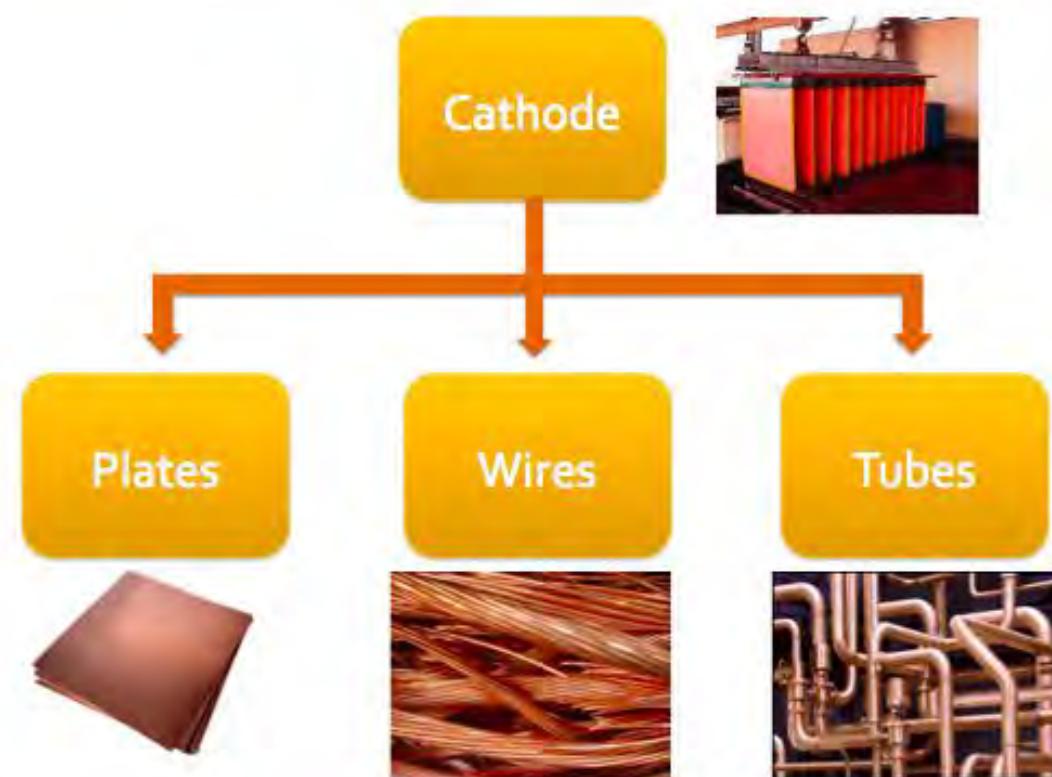
Source: <http://www.outotec.com/pages/Page.aspx?id=38a86&epslanguage=EN>

Electrolytic Refining

- Fixed capacitor consisting of two electrodes separated by electrolyte
- Process of purifying metal plates that are suspended as anodes in electrolytic bath



<http://www.citycollegiate.com/ldblock4.htm>



Conclusion

- Copper mining contains both positive and negative impacts on the environment and among people

Discussion Questions

- How does copper affect your everyday lifestyle – how long could you go without using copper?
- Do you think mining on tribal lands is a benefit or a misfortune – why?
- If you had \$1 billion dollars, would you invest it in a potential mine or the stock market – why?
- Why are the processes for getting these ores out so different? Which is more resource-intensive? Are there any steps that could limit waste?

Copper



Hands-On Activity

A laboratory experiment for college students

The Chemistry of Copper Electrolysis

Objectives

1. Apply basic chemistry principles to understanding the process of electrolysis.
2. Understand how electrolysis is used in the processing of copper ores.

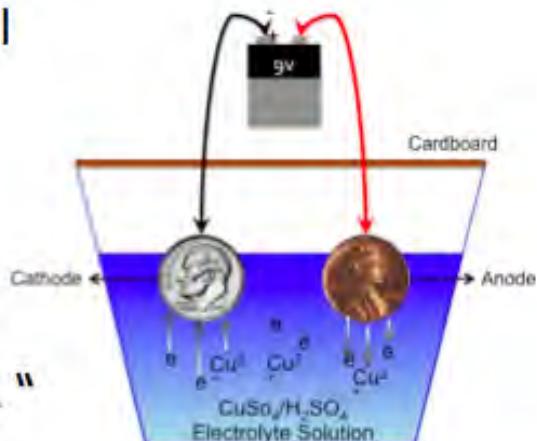
Electrolysis

- Uses an electrical current to move ions in an electrolyte solution between two electrodes
- In copper electrolysis, when current is applied, +copper ions (cations) leave the anode (+electrode) and move toward the cathode (-electrode)



Hypothesis

- What do you think will happen in this experiment?
- Write a hypothesis in Worksheet (page 7)
- Example:
"I hypothesize that "



Electrolysis Lab Experiment

- Coating the dime with copper from a penny
 - Electrical current applied to penny and copper cations are set free in the electrolyte solution. Cu^{2+} attracted to the dime which is connected to the -terminal of the battery



Anode
Positive Electrode
 $\text{Cu}_{\text{solid}} \rightarrow \text{Cu}^{2+}_{\text{aqueous}} + 2 \text{e}^-$



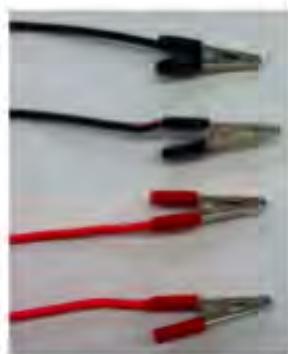
Cathode
Negative Electrode
 $\text{Cu}^{2+}_{\text{aqueous}} + 2 \text{e}^- \rightarrow \text{Cu}_{\text{solid}}$

Materials



Procedure

1. Clean the penny with salt/vinegar mixture, rinse with water and dry
2. Insert each folded end into handle of matching alligator clip



Procedure

3. Weigh each coin/copper wire assembly and record the mass in Table 1
4. Pour 200 mL of the copper sulfate electrolyte solution into the beaker.

Careers in Mining

■ **Mine Operations**

- *Design, build, and operate surface and underground mines, work in mine finance, and work with mine information and production technology.*

■ **Geomechanics**

- *Work on geotechnical and geomechanical designs and projects in rock and soil.*

■ **Sustainable Resource Development**

- *Involves health and safety, environmental science, or a range of classes related to sustainability including resource economics and anthropology.*

■ **Mineral Processing**

- *Gain an in-depth knowledge of ore comminution and liberation, removal of the valuable minerals in the form of concentrate, extraction of valuable metals from concentrates, and purification of metals using aqueous or thermal chemistry.*

<http://www.mge.arizona.edu/undergraduate-program>

Lab Procedure

- B. Carefully remove wire assemblies and hang to dry in an empty beaker until dry (~5-10 min)
- g. Examine changes in coin and weigh



Lab Results



Initial mass of dime [g]	3.549	Initial mass of penny [g]	4.764
Final mass of dime [g]	3.988	Final mass of penny [g]	4.371
Difference in mass [g]	+0.439	Difference in mass [g]	-0.393

Lab Questions

- 1. At the end of the experiment, the dime should be coated with copper. What are the possible sources of this coating? How could you determine which sources contributed to the coating, and how much?
- 3. Why do you think copper wire is used for the coin/wire assemblies?
- 6. To reach commercial scale, how do you think you would need to change the materials from this small experiment to make a 300 lb copper cathode?

Thank you!



DOI

Baboquivari Peak is the most sacred place to the Tohono O'odham people. It is the center of the Tohono O'odham cosmology and the home of the creator, I'itoi. According to tribal legend, he resides in a cave below the base of the mountain.

Hands-On Activity Protocol

The Chemistry of Copper Electrolysis

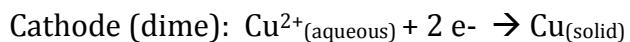
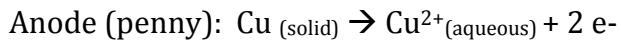
Overview:

This experiment demonstrates the process of **electrolysis***, which is in the commercial purification of ores such as **copper**.

Electrolysis uses an electrical current to move **ions** in an **electrolyte** solution between two **electrodes**. In copper electrolysis, when current is applied, positively-charged copper ions (called **cations**) leave the **anode** (positive electrode) and move toward the **cathode** (negative electrode).

In this experiment (Figure 1), a U.S. penny acts as the copper source and as the anode and a U.S. dime serves as the cathode. (A dime, versus another penny, makes the movement of copper more obvious). A dilute **aqueous** solution of copper sulfate and sulfuric acid is used as the electrolyte. An electric current is provided by a 9V battery.

When electric current is supplied to the anode (penny) via the positive terminal of the battery, copper atoms are **oxidized** to form cations with a positive charge (Cu^{2+}). The cations are set free in the electrolyte solution and are attracted to the cathode (dime), which is connected to the negative terminal of the battery. Additionally, the copper sulfate electrolyte solution contains copper in the form of positively-charged cations, which are also attracted to the negative electrode (*i.e.* the cathode, a dime).



This results in the net loss of copper from the anode (penny) and the gain of a copper coating on the cathode (dime).

Objectives:

- Apply basic chemistry principles to understanding the process of electrolysis.
- Understand how electrolysis is used in the processing of copper ores.

Time Required:

30 minutes to set up; one period to complete.

Materials:

- Copper sulfate electrolyte solution (200 g $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ + 25.0 mL concentrated H_2SO_4 solution in enough distilled or deionized water to make 1.0 L of solution)
- Coin cleaning solution (1 tsp table salt dissolved in $\frac{1}{4}$ cup vinegar)
- Pre-1982 penny (contain 95% copper, compared to only 2.5% copper post-1982)
- Dime (any year)
- 9V battery (will need a new 9V battery for each experiment)
- 18-gauge copper wire
- Four alligator clips (2 each of red and black)
- Wire stripper and needle-nosed pliers
- (2) 250-mL beakers
- Cardboard square (approx. 15 cm on a side)
- Scale (optional)



Figure 1. Materials needed for copper electrolysis lab.

Hazards:

Glove and goggles should be worn throughout this experiment. Sulfuric acid can cause burns; handle with care. Although the power source is relatively weak, the electrodes and connecting wires should not be handled when the cell is operating. The 9V battery can become quite hot during use; use caution when handling it.

Protocol:

1. Clean the penny with salt/vinegar mixture; rinse with water and dry (dime does not need to be cleaned).
2. Prepare two connecting wires:
 - a. Cut a 33 cm length of 18-gauge copper wire.



Figure 2. 33 cm length of 18-gauge copper wire.

- b. Peel apart to separate red- and black-coated wires.



Figure 3. A) Peelings apart red and black coated wires. B) Separated red and black wires.

- c. Use 1.6 mm gauge setting on wire stripper to remove ~ 1.5 cm length of rubber coating from both ends of each wire to expose the copper filaments being careful not to sever copper filaments.



Figure 4. A) Closed wire stripper; B) open wire stripper, and C) 1.5 cm length of rubber coating removed from copper wires to expose copper filaments.

- d. Twist filaments together tightly and fold in half.

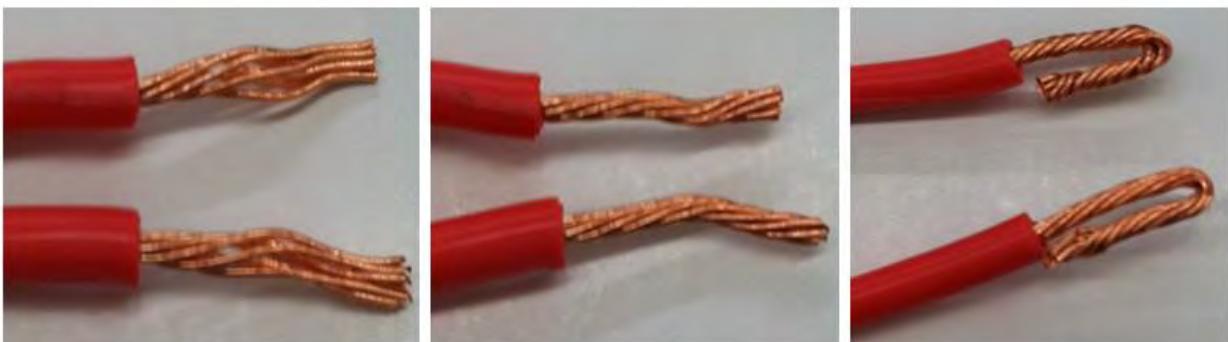


Figure 5. A) Exposed copper filaments; B) twisted copper filaments; and C) final product of twisted and folded copper filaments.

- e. Make two holes in the cardboard an inch apart from each other.
- f. Push the wires through the holes.
- g. Insert each folded end into the handle of a matching alligator clip so that the wire touches the metal inside the clip handle (red wire should have a red alligator clip at each end; black wire should have a black alligator clip at each end.)

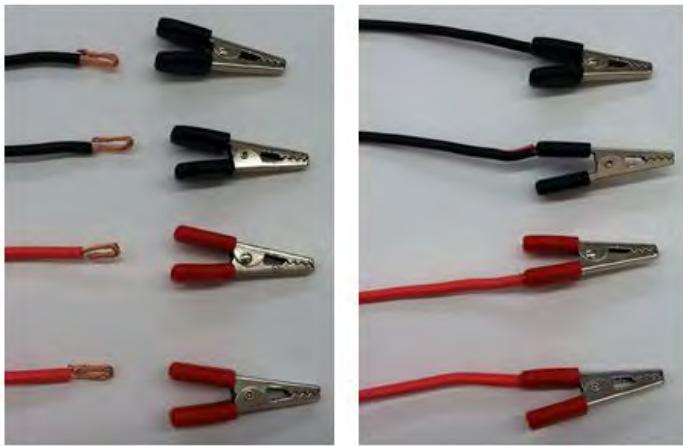


Figure 6. A) Unattached copper wires and B) copper wires attached to alligator clips.

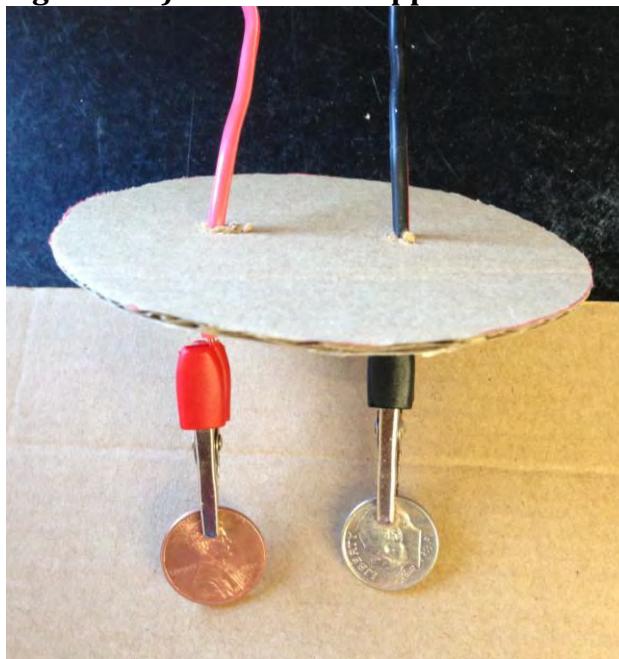


Figure 7. Red and black wire pushed through a cardboard with alligator clips attached.

3. Weigh each coin/copper wire assembly and record the mass (optional).
4. Pour 150 mL of the copper sulfate electrolyte solution into the beaker.
5. Place the square over the beaker so that the coin "electrodes" are immersed in the electrolyte solution as illustrated in Figure 8.

→ *Note:* the two electrode assemblies must not touch.



Figure 8. Electrodes immersed in the electrolyte solution

6. Clip one end of each connecting wire to the terminals of the 9V battery:
→ Clip red to the positive terminal, and black to the negative terminal.
7. Clip the other end of the connecting wires to the top of the copper wire assemblies:
→ Connect the positive terminal (red connecting wire) to the penny, and the negative terminal (black connecting wire) to the dime.

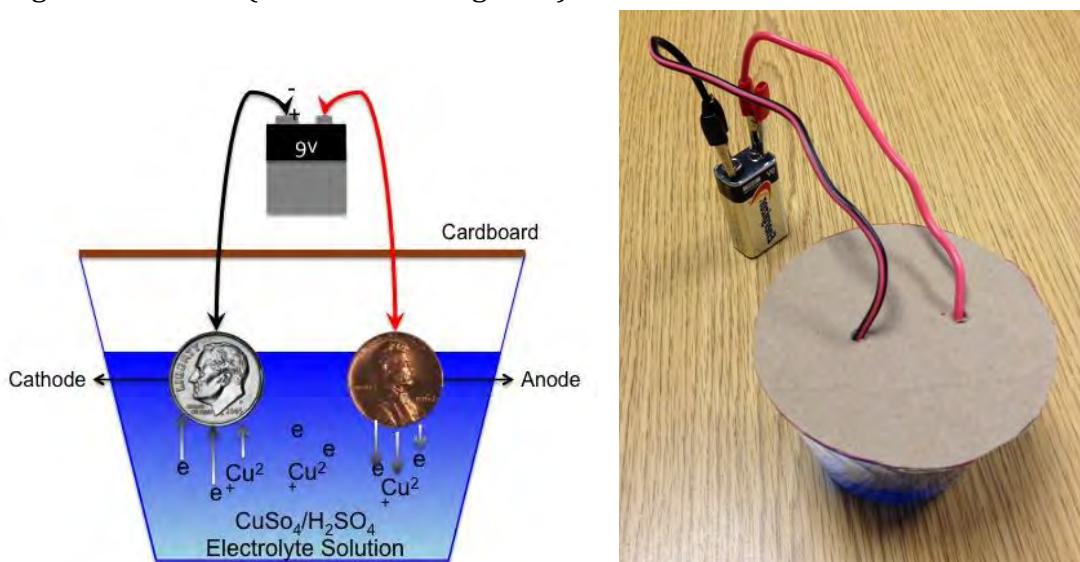


Figure 9. A) Cross section illustration of final copper electrolysis lab set-up. B) Actual copper electrolysis lab set-up.

8. Allow the **electrolytic cell** to operate for 5 minutes. Record the length of time the cell was operating (optional).
9. Remove the cardboard with the coin/copper wire assemblies and hang to dry in an empty beaker until it is dry (approximately 5-10 min), being careful not to touch, so as not to lose any of the copper plating.

10. Examine the coins for changes.
11. Weigh each coin/copper wire assembly and record the mass (optional). Calculate the difference in starting and ending mass (optional).

Disposal:

Coins used in this experiment should not be reused as currency. Coin/copper wire assemblies may be discarded in the trash or recycled. Electrolyte solution can be reused; to dispose of the solution, it should be flushed down the drain with plenty of water. 9V batteries can be disposed of in the trash – or you can contact your local household hazardous waste facility on whether they can be accepted for recycling. (For Pima County, see cms3.tucsonaz.gov/es/household_hazardous_waste for more information.)

Relevance:

For purifying copper commercially, a large slab of impure copper (called blister copper) is used as the anode and placed in an electrolyte solution of copper sulfate and sulfuric acid. A thin “starter sheet” of highly pure copper foil is used as the cathode. When current is applied, copper (as well as other metals) leaves the anode and moves through the solution toward the cathode. The other metals (sometimes valuable, but considered to be impurities in copper processing) either remain in solution or fall to the bottom of the tank, where they can be harvested as a by-product. At the cathode, the copper ions plate out, resulting in a 300 lb sheet of 99.9% pure copper.

Worksheet:

1. Write your hypothesis. My hypothesis:

2. Start Time: _____

3. End Time: _____

Table 1. Determining the mass of copper plating.

Initial mass of dime [g]		Initial mass of penny [g]	
Final mass of dime [g]		Final mass of penny [g]	
Difference in mass [g]		Difference in mass [g]	

Questions:

1. At the end of the experiment, the dime should be coated with copper. What are the possible sources of this coating? How could you determine which sources contributed to the coating, and how much?

Calculate the final concentration of CuSO₄ in the copper sulfate electrolyte solution.

Why do you think copper wire is used for the coin/wire assemblies?

What differences would you expect if the electrolytic experiment were allowed to run for a short time versus a long time?

What would you expect to see if you made the dime the anode and the penny the cathode, and/or used different coins in the experiment? Would you need to change anything?

2. To reach commercial scale, how do you think you would need to change the materials from this small experiment to make a 300 lb copper cathode?

Fill in the diagram below of commercial-scale electrolytic refining by labeling the anodes and cathodes, and by drawing in the movement of copper ions.

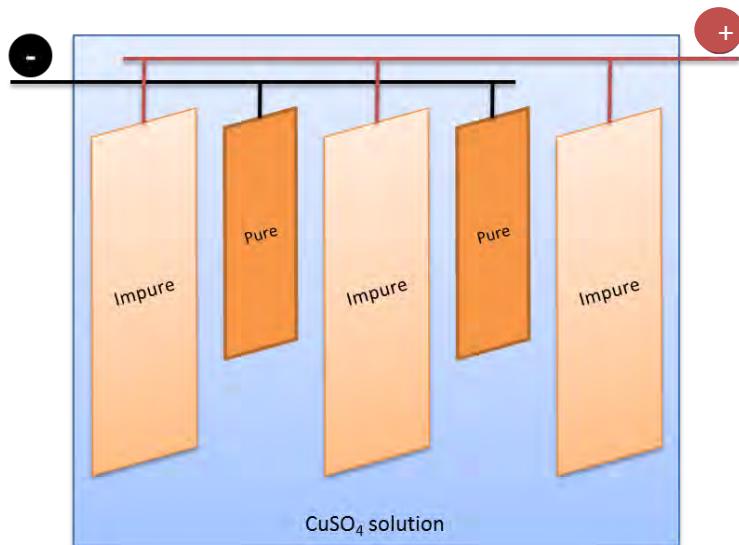
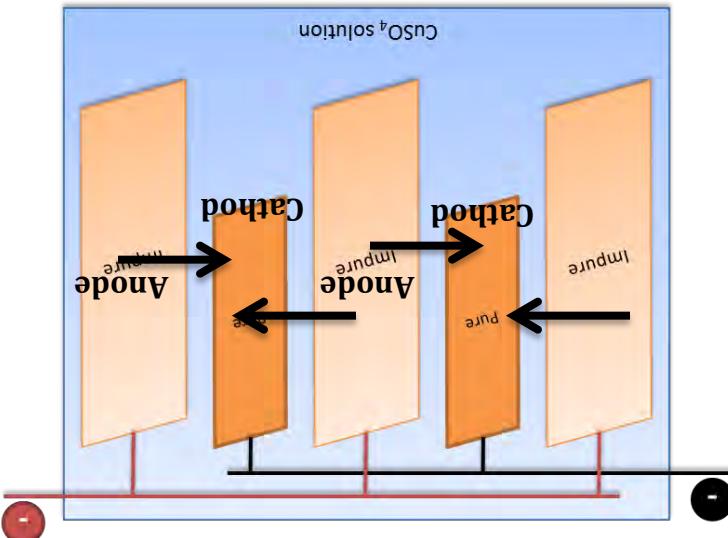


Figure 10. Diagram of commercial-scale electrolytic refinement.



6. Need to start with a high anode (i.e. not a pennie) might need to add more solubilities, they either remain in solution or precipitate out.

other metals are not plated in the commercial copper process - because of their different from different coins, would need to optimize the electrolyte solution for that metal. This is why copper, so you might still see it transferring to the penny. In order to make different metals move 5. Would have to know what the content of each coin is - modern dimes actually contain 4. The longer the experiment is run, the more copper plating will appear on the dime.

3. Because copper is known for its properties as an excellent electrical conductor (it should not contribute significantly to the plating of copper on the dime).

$$\frac{200\text{g}}{159.61\text{g/mol}} = 1.25\text{M}$$

g/mol

separately, so this determination cannot be made empirically.)

from the solution. Although the copper wires may also act as a source, they are not weighed from the penny does not account for the whole gain on the dime, it must have gotten copper after, students should be able to determine where the mass came from (i.e., if the loss of weight 1. Possible sources include the penny, the solution, the copper wires - by weighing before and

Answers:

Glossary:

Electrolysis – the movement of an electric current through a solution or substance, with subsequent migration of positively- and negatively-charged ions to the negative and positive electrodes, respectively.

Copper – a metallic element, having a characteristic reddish-brown color, which is ductile, malleable, and a good conductor of heat and electricity.

Ion – an electrically charged atom or molecule which can be formed by the gain or loss of an electron(s); whether the electrons are gained or lost is indicated by a minus or plus sign, respectively, and a number indicating how many. For example, Cu^{2+} has lost 2 electrons and carries a positive charge.

Electron – a subatomic particle that carries a negative charge.

Electrolyte – a solution or substance that conducts electricity; the flow of current may be accompanied by the movement of ions.

Electrode – an electrical conductor, through which a current enters or leaves an electrolytic cell or other medium.

Cathode – the electrode in an electrolytic cell, toward which positively-charged ions (cations) are attracted. The cathode has a negative charge in this experiment because it is connected to the negatively-charged end of an external power supply.

Anode – the electrode in an electrolytic cell, toward which negatively-charged ions (anions) are attracted. The anode has a positive charge in this experiment because it is connected to the positively-charged end of an external power supply.

Cation – a positively-charged ion that is attracted to the cathode in electrolysis.

Anion – a negatively-charged ion that is attracted to the anode in electrolysis.

Aqueous – relating to or dissolved in water.

Oxidize – to lose or remove electrons.

Electrolytic cell – A device that contains two electrodes in contact with an electrolyte and that brings about a chemical reaction when connected to an outside source of electricity.

Chapter 4

Conclusion

The objectives of this project were fulfilled within a 14 month time frame starting October 2011 and ended December 2012. A partnership was developed with the Tohono O'odham Nation and Tohono O'odham Community College to develop the educational module. Working closely with the tribe allowed the tribe to direct and guide the development of the educational module and to incorporate tribal perspective. A literature review was conducted to understand copper mining and processing and data was obtained from the Arizona Department of Mines and Mineral Resources to conduct an inventory on mines on and near the Tohono O'odham Nation. Using the literature review, an instructional guide on Copper, Copper Mining, and Copper Processing, a comprehensive supplementary PowerPoint presentation, and a hands-on activity was developed. Using expert reviewers, the educational module was refined using a technical review and the an excerpt of the educational module on "Copper Electrolysis" was presented to a Tohono O'odham Community College chemistry class.

Through the development of these educational modules for a tribal college, there were several lessons learned. They are as follows:

- A) **Refined Assessment:** The pre- and post- survey assessment conducted during the presentation at TOCC should have questions that align with the objectives of the lab protocol and the instructional guide. Having the questions align with the objectives lets the instructor know if the students comprehended the module and/or lab experiment.
- B) **Weekly Tribal Meetings:** A meeting every week with the tribe and/or tribal college such as Mr. Addison Smith would create constant communication, increased information gathering, and increased efficiency in module development. More work could have been accomplished when addressing important aspects pointed out by Mr. Smith. Weekly meetings would create an even stronger relationship with Tohono O'odham Nation by constantly and consistently working with them side-by-side.

In conclusion, the partnership built between Superfund Research Program and Tohono O'odham Community College and Tohono O'odham Nation proved to be successful and can be used as a model to build relationships with other Tribal Colleges within and outside the state of Arizona. When building a new relationship with a different Tribal College, the opportunity for TOCC to speak about their experience would be valuable to other Tribal Colleges and they may be more inclined to begin a partnership with SRP. Further work in this area could include maintaining the relationship with TOCC and the Tohono O'odham Nation to further address areas of concern. Maintaining this relationship could include continued meetings in Sells, AZ at TOCC and/or in Tucson, AZ at the University of Arizona. These meetings would allow further communication between the partners to adequately target educational gaps and needs (determining subject for educational module), ensure accurate information and quality of documents, and identify the type of curriculum to address different learning styles. Thus, a strong university-tribal partnership is necessary to ensure that the educational module are tribally directed and guided.

References

Associated Press. 2013. Silver Bell Mining Fined \$60K for Spill. Arizona Public Media. Available at: <https://www.azpm.org/p/top-news/2013/1/29/22054-silver-bell-mining-fined-60k-for-spill/> (verified 2013 April 21).

Allison, L. 2011. Two Arizona companies among 100 biggest mining companies. Arizona Geology Blog. Available at: <http://arizonageology.blogspot.com/2011/01/two-arizona-companies-among-100-biggest.html> (verified 2012 February 4).

Baxamusa, B. N. 2012. Uses of Copper. Available at: <http://www.buzzle.com/articles/copper-uses-of-copper.html> (verified 2012 February 2).

Cammarota, Jr., V. A. 1992. SME Mining Engineering Handbook. Society of Mining, Metallurgy, and Exploration, Inc. 2 (1), 63-80.

Copper Development Association. 2012. Copper and sustainability. Available at: <http://www.copperinfo.co.uk/environment/sustainability.shtml> (verified 2013 February 1)

Crescent City Copper. 2011. 15 Fun Facts About Copper. Copper Blog. Available at: http://www.crescentcitycopper.com/blog/Copper_Blog/post/15_Fun_Facts_About_Copper/ (verified 2012 February 2).

Dudka, S. and Adriano, D. 1997. Environmental impacts of metal ore mining and processing: A review. *Journal of Environmental Quality*, 26: 590-602.

Edelstein, D. L. 2012. United States Geological Survey Available at: <http://minerals.usgs.gov/minerals/pubs/commodity/copper/index.html> (verified 2012 November 21).

Freeport-McMoRan Copper and Gold. 2013. Our metals, what we mine, copper. Available at: <http://www.fcx.com/metals/copper.htm> (verified 2013 February 2)

Gault Group, Inc. 2008. Mining and reclamation plan. Available at: [https://www.asarcorg.com/Images/Mining%20and%20Reclamation%20Plan%20\(Exhibit%20F\).pdf](https://www.asarcorg.com/Images/Mining%20and%20Reclamation%20Plan%20(Exhibit%20F).pdf) (verified 2013 April 22).

Gunter, Joseph. 1999. Copper: Its Trade, Manufacture, Use, and Environmental Status. ASM International, Materials Park, OH.

Hartman, H. L. and Mutmansky, J. M. 2002. Introductory Mining Engineering. John Wiley and Sons, Inc. 2 (1), 6. Available at: http://www.cienciaviva.pt/img/upload/introduction_to_mining.pdf (verified 2013 April 19).

Hartman, H. L. 1992. SME Mining Engineering Handbook. Society of Mining, Metallurgy, and Exploration, Inc. 2 (1), 3-35.

Harmon, A., Oso, P., and S. Webb. 2013. Copper more than Metal. Available at: www.mii.org/pdfs/copper.pdf. (Verified 01 Feb 2013.) Freeport-McMoran Copper and Gold.

Holt, Rinehart, and Winston. 2004. Mining Regulations and Mine Reclamation. Environmental Science. Available at: http://www.nexuslearning.net/books/holt_env_science/16-3.pdf (verified 2013 April 22).

Leonard, A. 2006. Peak Copper? Salon. Available at: http://www.salon.com/2006/03/02/peak_copper/ (verified 2012 February 2).

Niemuth, N. 2011. 2010 Arizona Mining Review. Minerals and Mining. Arizona Geology Magazine. Available at: <http://azgeology.azgs.az.gov/article/minerals-and-mining/2011/09/2010-arizona-mining-review> (verified 2012 March 7).

Niemuth, N. 2008. Arizona Mining Update – 2007. Arizona Department of Mines and Mineral Resources, 1-8

Otto, J. and Cordes, J. 2000. Sustainable Development and the Future of Mineral Investment pg. 1

Papp, J. F. 2010. Recycling-Metals. 2010 Minerals Yearbook. United States Geological Survey. Available at: <http://minerals.usgs.gov/minerals/pubs/commodity/recycle/myb1-2010-recyc.pdf> (verified 2013 April 22).

Robertson, A. and S. Shaw, S. 1999. Mine Closure. Available at: <http://www.infomine.com/library/publications/docs/e-book%2002%20mine%20closure.pdf> (verified 2013 February 1). Infomine e-book.

Scott, J. 2012. General Mining and Copper Industry in Arizona story/Websites/Books/Manuscripts. Available at: <http://jeff.scott.tripod.com/mining.html> (verified 2012 April 26).

Scott, W. 2011. Methods and Techniques for Recycling Copper. Available at: <http://www.brighthub.com/environment/green-living/articles/66929.aspx> (verified 2013 April 22).

United States Department of Interior. 2012. Trustees Open 45-Day Public Comment Period on Phase II Draft Restoration Plan for Injured Natural Resources at Cyprus Tohono Mine, Tohono O'odham Nation. Available at: <http://www.doi.gov/restoration/news/cyprus-tohono-mine-phase-ii-draft-restoration-plan.cfm> (verified 2013 April 22).

Veiga, M. M., M. Scoble, and M.L McAllister. 2001. Mining with communities. Elsevier Science Ltd. 25 (1): 191-202.

Wood, V. 2001. A short history of copper mining. Available at: <http://www.exploringthenorth.com/cophistory/cophist.html> (verified 2012 April 26).

World Bank and International Finance Corporation. 2002. It's Not Over When It's Over: Mine Closure Around the World. Available at: <http://siteresources.worldbank.org/INTOGMC/Resources/notoverwhenover.pdf> (verified 2013 February 1)

Open Energy Info. 2013. Indian Mineral Development Act of 1982. Available at: http://en.openei.org/wiki/Indian_Mineral_Development_Act_of_1982 (verified 2013 February 1).

Open Energy Info. 2013. Indian Mineral Leasing Act of 1938. Available at: http://en.openei.org/wiki/Indian_Mineral_Leasing_Act_of_1938. (verified 2013 February 1).

Appendix A: Technical reviews from various experts

Anonymous 1

Slide 35 – even if the resource is proved, there is still risk. I would say low risk instead of no risk. I changed the text “no risk” inside the Proved box to “low risk.”

Slide 76 - 1st question: consider adding education/training as a +
I deleted this section on slide 76 because it does not coincide with the objectives stated at the beginning of the presentation.

2nd question – good; consider an additional question probing the fact that mineral deposits large enough to be mines are rare I did not change the second question. I just added questions that are align with the objectives.

3rd question - I'm not clear what the \$20M represents. Who is making that investment? You don't have any economics discussion in the slides so it's a question of net present value and return on investment for a mine and a casino but none of that has been covered in the slides. I'd save that question for the economics module. Consider replacing this question with the suggested question above. I deleted this question because it is previously mentioned in the presentation to be addressed in the discussion.

I would suggest you make the discussion questions align with the objectives listed for the module. I deleted and added questions that are align with the objectives:

- Why hasn't copper been replaced?
- What are the pros and cons of developing a deposit on tribal lands?
- Where would we be without copper?
- What are the five stages of copper mining? What do each stage entail?

Anonymous 2

Slide 26 (tohono) – the “area protected by the liner” is a repository for the materials removed from the former evap ponds and then stabilized in a cell and eventually capped. The former tailings area and the evap ponds were also regraded and capped.
I added these comments to the notes section of the slide.

Slide 38 – the 2-5 year time frame to permit a new mine is likely too short. 4 – 12 years is a more likely range.

On the Stage 3 Development slide I changed “2-5 year” to “4-12 years”

Slide 56 – the rubber liner in the diagram – in some cases, ADEQ has approved bedrock as a suitable liner material (no synthetic liner)

I inserted this text in the notes section of the slide and referenced Bill Cobb

Slide 76 - <\$20M in development costs can be low – the cost to complete permits, EISs, and feasibility studies could be several times that number

I deleted this section, as it does not align with the objectives stated in the beginning of the presentation.

Guide – same comments on the development costs and time frames

General feedback (which I provided when we met in Phoenix):

The cost of major mines is now in the several \$Billion range. For example, our MILL at Morenci is a \$1.4B project and does not include mining equipment, crushing/conveying equipment, or a tailing facility. We think that the Carlotta, Rosemount, and Mineral Park were in the \$600 - \$800 million range. I cant seem to find the public domain cost for our Safford mine built a few years ago but expect it to be in the same range. Given the total cost for bringing a major new mine through development and into production, the students should also be aware that land tenure, water rights security, and regulatory certainty are critical to making investments of this size and duration.

In the Module, it might be a good set of exercises for students to do internal research on projects being proposed for development around the work to understand why they are being proposed, the issues associated with them (many social issues will likely be found), and the costs. Because the location of mineral deposit is fixed (the company cannot change the location and therefore has to deal with the political/governmental risks of places like Peru, Africa, Far East/Asia, former Soviet bloc countries) students can evaluate the pros/cons of developing a deposit on tribal property versus developing one in Mongolia or Philippines, or elsewhere. They can also review projects that have been pulled by companies (most of the reason is escalating costs and poor returns on investment but political risk also factors into some of these).

Developed a question out of pros and cons of a developing deposit on tribal land into a discussion question.

Anonymous 3

Regarding the lecture notes, I think it is really important to cite the sources of any figures/schemes that you may have taken from books/web sites, etc
I cited the figures and tables in the lecture in the references.

After slide 11

Slide showing main countries producing COPPER in the world

I added a slide of a map of the countries that mine copper in 2010

Slides 30 and 31

It would be nice if these slides could include some figures or pictures

I added images to slide 30 and 31 to help visually see the steps in the stages.

Slide 61

Typo on title

I corrected the typo of the word Flotation

Slide 41, you should consider removing it, it is the same as slide 43

I removed slide 42 and 43 because of the redundancies of slides.

Slide 42

Show later than the processing steps for Cu oxides and Cu sulfides have been explained
I did not incorporate this suggestion, as it would make the organization of the slides out of order.

Slide 43, show it after slide 46

I did not make this change because it would be confusing.

Section on Cu concentration is probably too detailed (Slides 64-73),

CONCLUSIONS

“copper mining contains both positive and negative impact on the environment.....”

This conclusion is not really based on the information provided in the presentation

The presentation focuses on ‘Cu mining and processing’ and provides data on economic benefits (employment, etc).

I would suggest including some data about ‘water usage’ by Cu mining/processing + general information on environmental impacts (dust, water contamination, landscape issues, etc)

I did not include and data about ‘water usage’ because that information will be included in the next module.

Anonymous 4

Slide on Mines on TO Land (Slide 24)

- Allison
- Reward (copper, gold, silver) is an abandoned mine
- Alison and Reward are a couple of numerous abandoned mines on TO
- Number of rock & gravel mines including Orizaba which mined gold in the 1880's
- Pioneer operated it as a landscape rock mine up 2 years ago and it reverted back to the tribe.

Slide on The modules you develop (Slide 3)

- You covered 1st bullet point but Addison suggested Economics of mining module.
Will you do this module?

Lab

- In real copper processing mine, the Anode –lead and Cathode – starter plate and the Copper is in solution. In the experiment the Copper comes from penny or from dime but in practice the copper is in the solution. The question about where the copper comes from either from solution or wire or dime is not accurate. Should clarify the experiment is different from real-world

Anonymous 5

1) do not use copper wire to hold the coins. Use the alligator clips and submerge the coins only half way. This will force copper from the penny to plate onto the dime instead of the copper wire.

- 2) use a 1.5V battery instead of 9v because using a high current will tarnish the copper.
- 3) look at journal of chemical education for already made experiments on electrolysis.