CHAPTER 2 - LIFE CYCLE ASSESSMENT OF COPPER PLUMBING PIPES

2.1 Introduction

In this chapter, copper plumbing pipe is analyzed from a life cycle assessment (LCA) perspective. Life cycle assessment is a system-wide or "cradle to grave" analysis encompassing all aspects including the final disposal. The characteristics and procedures of standard LCA are fully described in this chapter. Though LCA methodology has now been standardized by the industrial Standards Organization (ISO 14000), the physical data are not generally available for mines and mineral processing industries. The processes of mining, extracting, smelting/refining are very diverse across the world and the manufacturing processes of the pipes also vary in different plants and countries. Therefore, in this chapter, instead of a formal LCA, a complete overview of the copper pipe from the life cycle perspective is presented. It's known that a major part of drinking water copper pipes is recycled as well as made from recycled copper. This chapter includes discussions related to copper mining, manufacturing process, and recycling. The LCA methodology related sections in this chapter closely follow Heijungs, Huppes, Udo de Haes, Van den Berg, and Dutilh (1996; Life Cycle Assessment: what it is and how to do it, United Nations Environmental Programme, Paris, France).

2.2 Life Cycle Assessment (LCA)

Life cycle assessment (LCA) is the process of evaluating the effects that a product has on the environment over the entire period of its life cycle according to the definition of ISO 14000. LCA considers the whole life cycle of the product or its functions, covering all the processes: extraction and processing; manufacturing, transport and distribution; use, reuse, and maintenance; recycling and final disposal are included in LCA. These characteristics enable LCA to be an environmental decision making tool that provides additional information. This complicated procedure attempts to provide better objective answers that can yield sustainable types of production and consumption.

2.2.1 LCA application

LCA's results regarding environmental impacts of product's life cycle will provide decision rules combined with economic effects, convenience to customers, and safety. It facilitates communication regarding the environmental aspects of products, production design, production improvements, eco-labeling criteria, and policy strategies. When there are disputes related to environmental impacts between governments and Non-governmental organizations (NGO), LCA serves as a facilitator in terms of its unbiased scientific and quantitative nature.

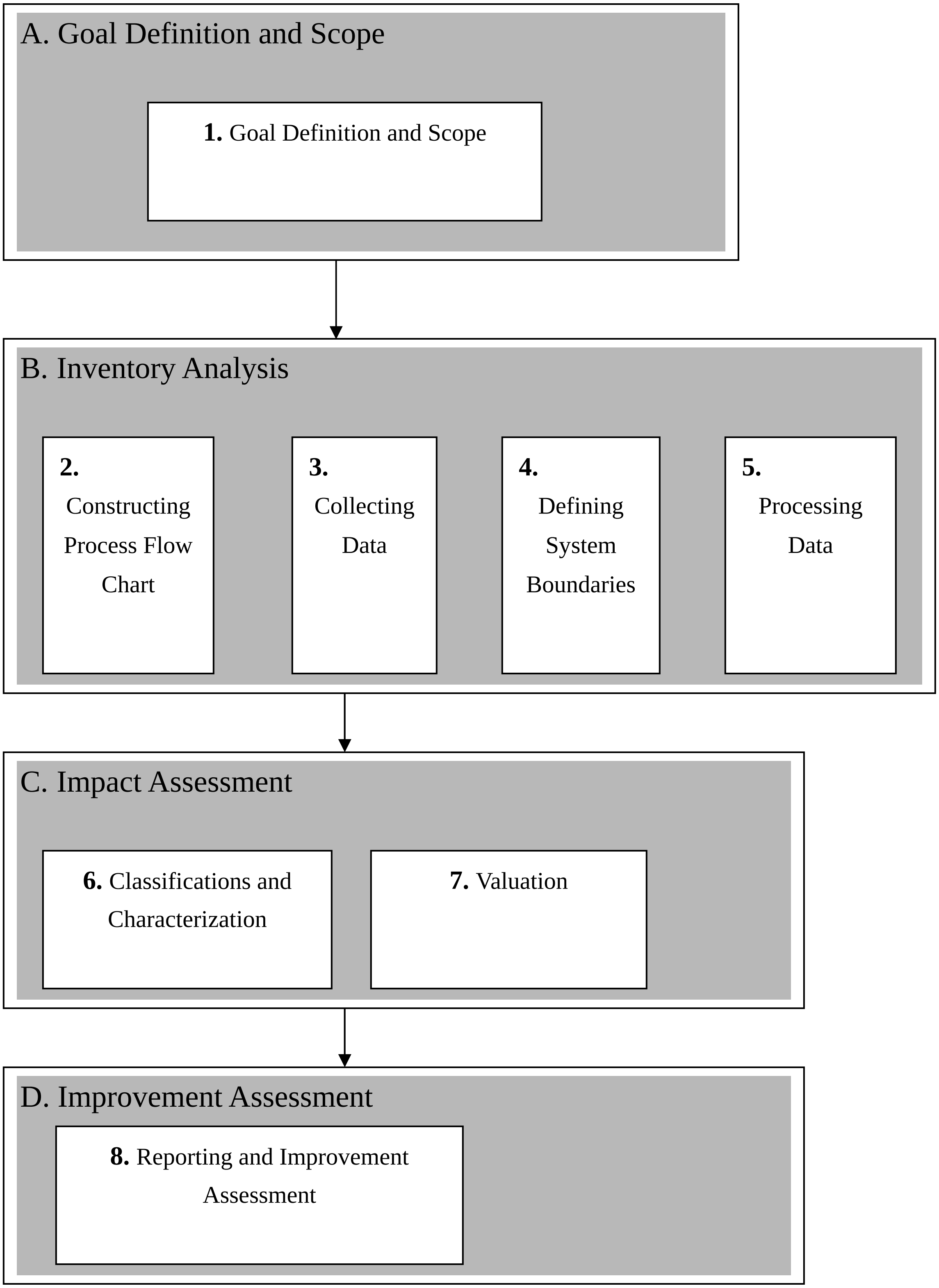

Figure 2.1 Main framework of LCA (SETAC LCA framework)

2.2.2 Main Framework of LCA

SETAC (Society of Environmental Toxicology and Chemistry) is the lead agency responsible for coordination and harmonization of international LCA activities. The standard LCA framework is shown in Figure 2.1. As shown in Figure 2.1, LCA is composed of four processes: defining the goal and scope of the study, inventory analysis, impact assessment, and improvement assessment. LCA is usually an iterative process. At first, a superficial analysis is performed with approximate data. Then with this rough assessment, performance enhancement is achieved by focusing on specific points where one desires improvement. The improved results are used as the basis for even more detailed study. As the types of applications and degrees of detail can be different, it's important to know what level of sophistication is required.

Goal definition and scope

Goal definition and scope of the LCA framework involves drawing up a specification of the study, how it is investigated, and how it'll be performed. Usually the LCA can have objectives as decisions on pros and cons of a product, production improvement, and the comparison of the products. As mentioned above, the scope of an LCA is related to the level of sophistication required for the goal of the study. If LCA results are intended for external use, a meticulous study including independent quality assurance is needed. The unit of product or function to be compared is referred to as the 'functional unit'.

Inventory analysis

The inventory analysis elaborates detailed procedures required in the manufacturing, use and eventual disposal of a product. These processes constitute the life cycle of that product. All the processes require inputs and produce outputs.

Constructing process flow chart

The first task in inventory analysis is to construct a process flow chart of all the processes involved in the product life cycle. All processes start with the extraction of raw materials and energy from the environment. They go through several stages of production and consumption. Eventually, they end at disposal sites. But growing rate of material recycling causes an increasing number of product systems that involve their own life cycle processes within a larger LCA study.

Collecting the data

Next step is to collect data on each process. Quantified data of inputs and outputs from each process need to be obtained from the literature and published data. Collecting the data is known to be time consuming and difficult task in an LCA activity.

Defining the system boundaries

After flow charting and data collection are done, the next step is to define the system more precisely by defining its boundaries. LCA can be reduced to a manageable size by omitting processes that fall outside of the boundaries. For example, copper pipes can be made from the scrap metals or from copper mining. Depending on the purpose of the LCA, the system boundaries can be defined differently. Much care is needed when defining the system as slight differences can have substantial influence on the results.

Processing data

The last stage of the inventory analysis is to adjust the values of the inputs and outputs from each process which is related to each functional unit using an appropriate transformation into a convenient form. For example, all emissions of CO_2 are identified for the whole system, added up and entered in the inventory table as ‘y kg of CO_2’. This table contains the environmental inputs and outputs. This inventory analysis is the main component of the LCA. It requires the most data and takes significant amount of time (Heijungs, 1996). The standard forms for inventory analysis can be found in Table 2.3.

Impact assessment

Impact assessment is for the interpretation of the impacts from the inventory analysis on the environment. To thoroughly assess the products investigated, the environmental effects must be compared. Impact assessment is composed of three steps; classification, characterization, and valuation.

Classification

In classification step, all the inputs and outputs are classified according to the different environmental problems they can cause. The significant problems usually are: resource depletion, energy depletion, global warming, acidification of soil and lake, photochemical oxidation, human toxicity, ozone depletion, and nitrification. Each input or output can contribute to several types of problems. For example, NO_2 emissions can influence global warming, acidification, and human health simultaneously. Various kinds of environmental problems and their characteristics can be found in Table 2.5.

Characterization

Next step is characterization. In this process, quantification of the contribution to each major environmental problem is done. For this, equivalency factors which indicate how much substances contribute to a problem compared to a reference substance are used. For example, the reference substance of the global warming is CO_2. Methane's effect on global warming can be expressed in terms of equivalent amount of CO_2 which would have the same effects. If the value is 9, then 1kg of methane has the same global warming effects of 9kg of CO_2. Regarding the location (certain substances impacts on specific sites) and the fate of the substance is the area that's still being researched. After this step, next is the normalization which is optional. This is done by dividing the score for environmental problem such as energy depletion or global warming by the annual rate of it (Heijungs, 1996). The basic scheme for classification and characterization can be found in Table 2.6.

Valuation

The last step of the impact assessment is the valuation. It involves the total comparison of the environmental problems to which each product contributes. By weighting each environmental problem in terms of its importance, the results can be a single environmental index. In assigning the weighting factor, there's much subjectivity involved. For example, which has heavier impacts between global warming and acid rain? Characterization is designed to incorporate scientific or empirical knowledge on environment, but valuation is more based on social preferences at that time.

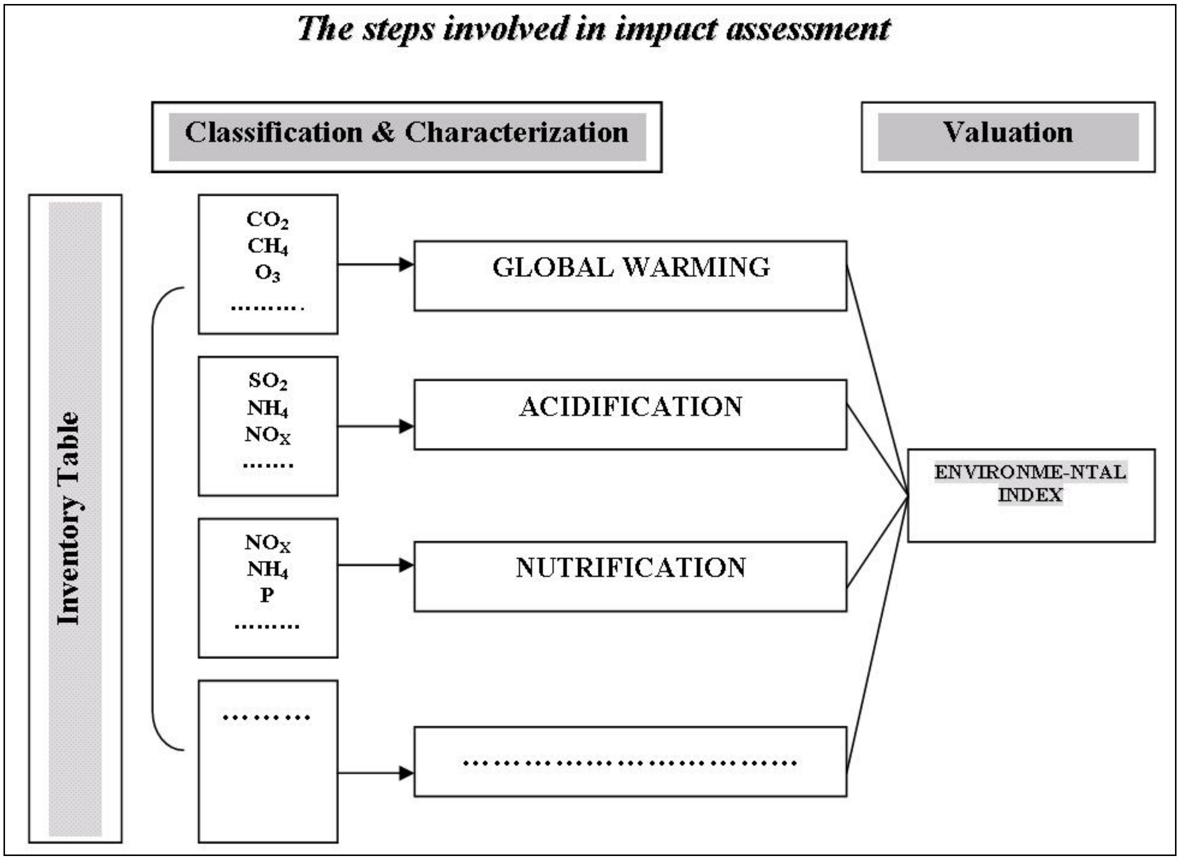

Figure 2.2 Impact assessment (Modifed from Heijungs, 1996)

Improvement assessment

The final goal of the LCA is to improve environment through better production, consumption, and sustainable development. This analysis starts with the most important areas where improvements can be made. At this stage, it can involve an assessment of economic, ergonomic and other aspects of the products. By repeating these aforementioned procedures, the product system can be improved and optimized.

2.3 Characteristics and Origination of Copper

Historically and technologically, copper has been very important metallic element to humans. Copper's ability to conduct electricity, corrosion resistance, malleability, ductility, and strength has made it as the indispensable element. From ancient times, copper has been used for weapons, tools, and copper alloys. Even today, copper has its vitality in various areas such as electroplating, plumbing, electric motors, and so on (CRC Handbook of Chemistry and Physics, 1994).

2.3.1 Properties of copper element

Copper's atomic number is 29 and it belongs to the 1B group in periodic table. Silver and gold are also in 1B group, and they have some properties in common with copper. In thermal and electrical conductivity, silver and copper are the first and second. Third and fourth are gold and aluminum respectively, but copper excels these elements significantly.

Though copper oxidizes in air, it is known to be highly corrosion resistant. It has a high melting point of 1083°C with a high boiling point of 2595°C. Pure copper is very ductile and can be easily drawn into wire. Copper alloys are formed in order to increase its strength, but it is known that most alloying elements reduce the thermal or electrical conductivity of copper significantly.

Copper has several valence states, ranging from 0 to +3. Pure copper Cu (0) is very stable. It oxidizes to $Cu(I)_2O$ (cuprite), which is black and unstable. With heating, the cuprite oxidizes to normal Cu (II)O (cupric oxide), which is quite stable and insoluble. Some other salts notably the sulfate, $CuSO_4$, are extremely soluble. The attractive blue-green patina on exposed copper surfaces consists of several compounds, depending on the surroundings. For example, in marine environment where there is salt in the air, atacamite $Cu_2(OH)_3Cl$ is likely to be formed. Corrosion of copper will be explained in more detail in Chapter 3. Copper is known to be quite biologically active (Ayres 2002, AWWA 1996).

2.3.2 Sources of copper

Several kinds of ores provide most of the copper in this world. The dominant copper ores are sulfides (sulfur (S) compounds), bornite (Cu_5FeS_4), chalcocite (Cu_2S), and chalcopyrite ($CuFeS_2$) . Azurite ($2CuCO_3$. $Cu(OH)_3$), cuprite (Cu_2O), and malachite ($CuCO_3.Cu(OH)_2$) are oxidizes ores that also yield significant amounts of copper. These ores also contain lead, zinc, gold, cobalt, and platinum in addition to copper. Usually copper ores contain less than 4 percent of the metal.

On world-wide scale, approximately 12 million tons of copper are mined each year. Copper deposits are located in almost every continent and especially mountain ranges extending from Alaska to the tip of South America where copper is most abundant. In most places nowadays, large open-pit mining is used (Ayres, 2002).

Leading producers

Chile is the world's largest copper-producing nation, mining about a third of the world's supply. The Unites States mines about a sixth of the world's copper and ranks second in the world production. US uses more copper than it mines, and it imports copper from other countries such as Canada, Chile, and Peru. Most of the copper mined in the Unites States comes from Arizona. Other countries with large deposits of copper are Indonesia, Australia, Canada, China, Kazakhstan, Mexico, Poland, and Zambia. In Table 2.1, the leading copper producing countries are listed (Ayres, 2002).

Table 2.1 World Copper Production (in Million Metric tons Cu content)

(Original Source: USGS Mineral Commodity Summaries, “Copper”, 2001)

Country	Production
Chile	4.382
United States	1.660
Indonesia	0.740
Australia	0.735
Canada	0.614
Peru	0.536
Russia	0.530
China	0.500
Poland	0.460
Total	**12.600**

2.4 Recycling

Copper and copper alloys have been recycled with the knowledge that copper objects could be melted and cast into new objects. Weapons were recycled from decorative and household goods during the war, and after that time, they were turned back into household or other non-war related products. Since early days, recycled copper has remained a major source of copper in the United States. Today, the process of transforming unalloyed copper scrap into new copper products begins with purchasing copper scrap from scrap processors. There are mainly 2 kinds of scraps which can be utilized. First is No. 1 scrap and second is No. 2 scrap. No. 1 scrap contains more than 99% copper and is simply re-melted. It usually consists of clean, unalloyed, and uncoated copper solids. No.2 copper scrap must be re-refined and consists of unalloyed copper having a nominal 96% copper content, may include oxidized or coated/plated pieces and copper wire free of excessive oxidation. When copper scrap is about to be recycled, it is visually assayed and graded, and analyzed chemically when necessary. No. 1 scrap material is directly melted and in some cases brought to higher purity with fire refinement. Chemical analysis checks the purity level of the copper when the charge (material other than coke in a blast furnace) is fully melted, and the molten copper is deoxidized and cast into intermediate shapes such as billets, cakes, ingots for further processing. No. 2 scrap is usually electrolytically refined to attain the desired purity level. Before that, the scrap material is fire refined, melted and cast into anodes. These anodes are the raw materials used in cathode production. The anodes are then electrolytically refined, essentially an electroplating process in which the anode is electrolytically dissolved into a bath of sulfuric acid and then electroplated out of the solution onto a stainless steel sheet. Thin sheets of pure copper are pulled off the stainless sheet and placed between anode plates in other electrolytic cells where further electroplating transforms these anodes into 99.98% pure copper which builds up into cathodes as it plates out on the thin pure copper sheets. This pyrometallurgical process has been widely used. There's new hydrometallurgical method which is increasingly used today that includes SX/EW (Solvent Extraction/ Electro Winning) (source: CDA Technical Report: The U.S. Copper-base scrap industry and its by-products-2001 and website www.copper.org).

Copper alloys are also recycled. Alloy scrap has to be segregated and scrap of unknown composition may be melted and analyzed to determine its composition. Then, alloy recycling is done by melting together scrap of known composition. From CDA (Copper Development Association) statistics, it's known that scrap consumption over the past 20 years has ranged between 44 and 54.7% of the total copper consumed in the US each year. The largest category of scrap is customer returned new scrap which is directly remelted during the process. The recycling rate of old scrap tends to fluctuate depending on copper prices and other economic situations. Recovery rates of old scrap decline when copper prices are low. Old scrap consists of discarded electric cable, junked automobile radiators and air conditioners and countless other products. (CDA Technical Report: Copper-base Scrap Industry and its By-Products, 2001)

2.5 Process technology

In the mining spot, copper ore in the form of large boulders are loaded with huge power shovels into trucks. And they're carried to the mills. Generally, all the processes are designed to separate valuable minerals from the ore and waste rock to extract copper and other metals that may be in the resulting mixture, and to purify these metals even though all the processes are not same. In a typical process, the ore is sent to the mill, where it is crushed and the waste rock removed. The resulting material is then sent to the smelter, where the metallic copper is separated from impurities. This copper may contain other metals, such as gold, silver, and nickel that must be removed by refining.

There are two ways to extract copper, one is pyrometallurgical and the other is hydrometallurgical. Pyrometallurgical method follows milling, smelting, and electrolytic refining whereas hydrometallurgical method involves milling, leaching, and SX/EW (Solvent Extraction, Electrowinning). The former is used about 80 percent and the latter is used around 20 percent in US for copper processing. But due to environmental issues, the combination of pyrometallurgical and hydrometallurgical methods is in increasing use (Ayres, 2002). The detailed procedures are given in the following and are adopted from Ayres (2002) and CDA website www.copper.org.

Milling

Milling starts in a crusher, where the ore is broken into small pieces. Then water is added to the crushed ore to form a slurry. The slurry passes into ball mills which are drum-shaped cylinders partially filled with iron balls. As the cylinders rotate, the balls grind the ore into particles small enough to pass through a screen with 10,000 openings per square inch. The slurry next goes through a flotation process that concentrates the mineral-bearing particles. There, chemicals and oil are added, and the entire mixture is agitated with air to make it bubble. The bubbles rise to the top of the cell with the particles and form froth. This froth is skimmed off and dried. The product, called copper concentrate, may contain from 15 to 33 percent copper. The waste material, called tailings are not attached to the bubbles. It is emptied from the lower part of the flotation cell and sent to storage ponds (source: www.copper.org).

Smelting

Smelting removes most of the remaining impurities from the copper. In smelting, copper concentrate is dried, and then blown with air and pure oxygen into a flash smelting furnace. In the furnace, the concentrate burns and melts, releasing some impurities in the form of sulfur dioxide gas. The molten material falls to the bottom of the furnace, where it separates into slag and copper matte. Slag, which contains iron oxide, silica, and other impurities, rises to the surface. Then the slag is discarded. Copper matte is heavier and collects under the slag. Copper matte contains 50 to 75 percent copper. It also contains some impurities in the form of iron sulfide and other metals. In the next stage of the process, the molten matte goes through a converter. In the converter, blowers force air through a converter and silica is added. The silica combines with the impurities, forming slag. The slag is again skimmed from the top. The new mixture is called blister copper which is 97 to 99.5 percent pure. The blister copper is refined in a fire-refining furnace. This furnace removes most of the remaining impurities, mainly oxygen. When natural gas is blown to melt copper and the natural gas (mostly methane) burns, oxygen and other gases are removed from the copper. The resulting copper is 99.9 percent pure (source: www.copper.org).

Electrolytic refining

Copper to be used in electrical conductors must be electrolytically refined to a purity of more than 99.9 percent. To do this, fire-refined copper is cast into cakes about 3 feet square and 2 inches thick. The cakes serve as anodes in the electrolytic process. The copper anodes are put into tanks containing a solution of copper sulfate and sulfuric acid. They are suspended alternately with cathodes, which are thin sheets of pure copper. When an electric current passes through the tank, the anode bars gradually dissolve, depositing copper more than 99.99 percent pure on the cathodes. Most of the remaining impurities in the anodes settle to the bottom of the tank and form sludge. After electrolysis, the copper cathodes are usually melted in a furnace and cast into various shapes and sizes (source: www.copper.org).

Leaching

It is a method of dissolving metal out of ore with a chemical solvent. Leaching recovers copper from ores that do not react to the chemicals used in the flotation process. In leaching, water containing sulfuric acid or other chemicals circulates through the ore and dissolves the copper. The solution is then mixed with a kerosene solvent containing chemicals that extract the copper. The mixture separates and the copper-bearing chemicals flow into a sulfuric acid solution. This solution is put into a tank to undergo solvent extraction-electro winning, a process similar to electrolytic refining. The resulting copper is about 99.9 percent pure (Ayres,2002).

Solvent Extraction and Electro Winning (SX/EW)

The copper-laden solution is treated and transferred to an electrolytic process tank. When electrically charged, pure copper ions migrate directly from the solution to cathodes made from pure copper foil. SX-EW is different from pyrometallurgical methods in that the anodes are inert. Hydrometallurgy (known by SX/EW) is the separation of a desired metal from an ore or concentrate by dissolution and later precipitation or electro-winning. This method is in rapid growth as of environmental and economic aspects. (Ayres, 2002)

2.6 Uses of copper products

Fabricating plants for brass and wire mills make semi-finished forms including sheets, tubes, and wires. They make these forms from copper rods, cakes, ingots, and billets. Manufacturers of copper products buy the semi-finished forms from these plants. About 35% of copper consumption in the United States is for electrical equipment. 32% is for fabricated metal products which include plumbing and pipe fittings. Machinery other than electrical is around 13 %, and transportation equipment constitutes 12 %. Miscellaneous uses account for less than 8% of the sales. In electrical equipment, high conductivity copper is indispensable. Copper is widely used in plumbing materials because of corrosion resistance, malleability, fire safety, and economy (www.copper.org). More details about copper plumbing are given in a later section.

Alloys and compounds

Copper can be mixed well with other elements, and there are more than 1,000 different alloys. The presence of the other element or elements can modify the tensile strength, corrosion fatigue, and wear resistance of the copper. One of the most important groups of copper alloys is brass which is the combination of the copper with zinc. And with the addition of tin, the base metal bronze can be made. As with the zinc in brass, the percentage of tin in bronze is variable, and according to different compositions, the resultant property varies.

2.7 Characteristics of copper pipe and manufacture

In the US, more than 90% of the domestic plumbing system is made up of copper. It came into widespread use since 1930. Through many centuries, light, strong, corrosion-resistant copper tube has had a proven history of reliable service in installations. Here, main characteristics and methods of copper pipe production are explained. In this section, contents from CDA Copper tube hand book (2002) and website www.copper.org are adopted.

Types of pipes

Copper plumbing pipe is manufactured from Copper No. C12200 (99.9% Copper), in accordance with the requirements of ASTM (American Society for Testing and Materials) Standard B 88. Most provincial regulatory authorities require that copper tube for use in plumbing systems be Third-Party Certified for compliance with ASTM B 88. Types DWV(Drain, waste, ventilate), ACR(Air conditioning and refrigeration), Medical Gas, and Type G/GAS tube meet the requirements of ASTM B 306, ASTM B 280, ASTM B 819 and ASTM B 837 respectively.

Types K, L, and M tubes have actual outside diameters which are 1/8-inch larger than the nominal (standard) sizes which the tube is commonly called. For example, a 1/2-inch Type M tube has an actual outside diameter of 5/8-inch. Type K tube has thicker walls than Type L tube, and Type L walls are thicker than Type M for any given diameter. Table 2.2 provides the dimensions for Types K, L, and M tubes. Temper denotes the hardness and strength of a tube.

Straight lengths are primarily drawn temper, or as more commonly known, hard tube. Annealed temper tube is referred to as soft tube. It is usually in coiled form, but certain sizes are also available in straight lengths (CDA Copper tube handbook, 2002).

Table 2.2 Wall thickness and diameter of K, L, and M pipe (Source: Copper Tube Handbook, CDA (2002))

Nominal Or Standard Size (Inch)	**Outside Diameter (Inch)**	**Inside Diameter (Inch)**			**Wall Thickness (Inch)**		
		K	**L**	**M**	**K**	**L**	**M**
1/4	3/8	0.305	0.315	-	0.035	0.030	-
3/8	1/2	0.402	0.430	0.450	0.049	0.035	0.025
1/2	5/8	0.527	0.545	0.569	0.049	0.040	0.028
5/8	3/4	0.652	0.666	-	0.049	0.042	-
3/4	7/8	0.745	0.785	0.811	0.065	0.045	0.032
1	1 1/8	0.995	1.025	1.055	0.065	0.050	0.035
1 1/4	1 3/8	1.245	1.265	1.291	0.065	0.055	0.042
1 1/2	1 5/8	1.481	1.505	1.527	0.072	0.060	0.049
2	2 1/8	1.959	1.985	2.009	0.083	0.070	0.058
2 1/2	2 5/8	2.435	2.465	2.495	0.095	0.080	0.065
3	3 1/8	2.907	2.945	2.981	0.109	0.090	0.072

Copper plumbing pipe production

Manufacturing of the copper plumbing pipe has been improved for energy-efficiency and environmentally acceptable quality under stringent standards.

Raw materials

The raw material for the production of plumbing pipe is mainly copper scrap, newly refined copper or copper ingots. The choice of the raw material is dependent on the plant's technical capabilities, economic factors. The most common form of copper scrap is the recycled copper wire that has been stripped of its insulation or baled copper pipe that has been removed from destructed buildings. Another common form is the runaround scrap or home scraps which are generated usually in the mill itself. Only the No. 1 copper scrap can be used to make copper pipe. Industry-wide, about 64% of the copper in plumbing tube is derived from recycled scrap, although the percentage varies drastically among different mills. This type of high-quality scrap costs around 90% of the value of newly refined cathode as very little refining is needed for processing the metal to the required purity of the plumbing pipe (source: www.copper.org).

Melting

The charge of raw materials is melted in a furnace whose function is to melt the copper charge. If the raw materials are only in the form of cathode, refined ingot or home scrap, a shaft furnace is sufficient. But if the raw materials are scrap, reverberatory or other hearth-type furnaces are used because they have the ability to refine the copper prior to casting. In a typical operation using scrap as the raw material, the charge is melted and brought to temperatures between 2300 °F and 2400 °F, which are several hundred degrees above copper's melting point of 1981 °F. The copper is then fire-refined by contacting the melt with oxygen, which preferentially reacts with impurities to form oxides. These oxides, being lighter than the liquid metal, float to the surface, where they become trapped in slag. After the refining process and when the slag is skimmed off, only the pure fire-refined copper remains. This copper is now 99.9%+ Cu. It is of essentially the same purity as fire-refined copper produced from the ore. Samples are taken to check the progress and when purity reaches the level required by the specification ASTM B88, the metal can be cast. At the end of refining process, controlled amount of phosphorous is added to limit copper's oxygen content to remain within a reasonable range. This process is called the phosphorous deoxidization. It bears the designation C12200 under the Unified Numbering System (UNS) used to identify metals and alloys (source: www.copper.org).

Casting

In holding furnace or tundish, the molten metal is transferred from the melting or refining furnace. Holding furnace or tundish works as a casting process, and it is heated enough to maintain the molten metal at an appropriate temperature. Also, to protect the oxidation, liquid metal surface is covered with a blanket of graphite powder. In this process, copper is cast into large logs by continuous or semi continuous methods. For continuous casting, metal is poured into horizontally oriented cylindrical molds. And these force the copper to freeze quickly with cool water. Then the solidified chilled molds are withdrawn by gripping devices. At that time, a moving saw cuts the log into two-foot long sections as it emerges from the casting machine. These sections are called billets which weigh usually 400 pounds. Semi-continuous casting is the process when it is done vertically. When the length of the log reaches the depth of the pit beneath the molds, this process is interrupted. Molten metal is then added to the mold at the same rate that the floor is withdrawn downward. When the resulting logs reach the desired length, the mold is withdrawn upward, allowing the logs to be removed from the pit (source: www.copper.org). These processes are shown in Figure 2.3.

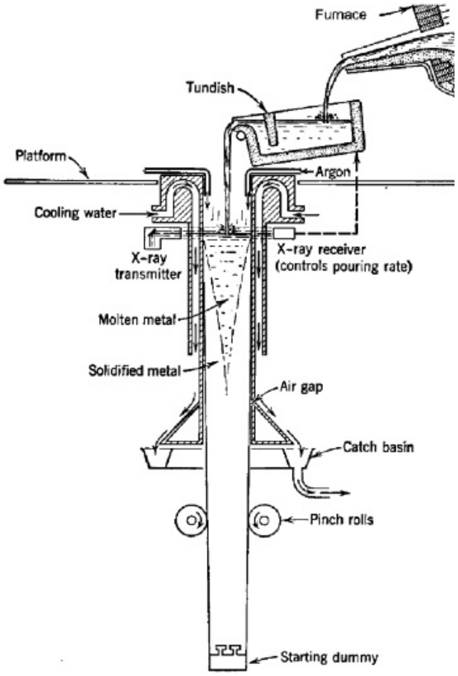

Figure 2.3 Vertical continuous casting (Source: www.copper.org)

Piercing

To make the copper pliable, the billets are reheated about 1535 °F. A piercing mandrel is driven lengthwise through the center of the billets what will become the inside wall of the plumbing tube.

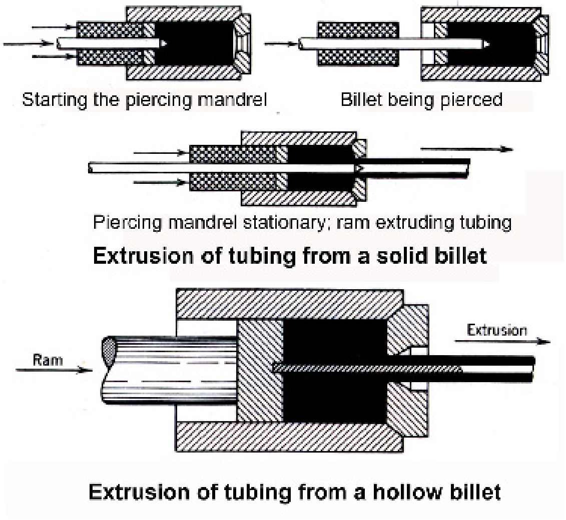

Figure 2.4 Extrusion (Source: www.copper.org)

Extrusion

The billet is placed in the chamber of an extrusion process, heated to the proper hot temperature. The chamber contains a die at one end and a hydraulic ram at the other end. The front face of the ram is fitted with a dummy block that is slightly smaller than the billet in diameter. As the ram moves forward, the copper is forced over the hole in the die and it causes a long hollow tube. These procedures are shown in Figure 2.4. The diameter and length can vary according the capacities of the mill. Metal near the surface of the billet extrudes backwards over the undersized dummy block, and this forms a shell which contains copper oxide, which is recycled to the refining furnace. Rollers carry the extruded tube emerging from the die so it remains straight until it is cool. And the tube is cleaned to remove surface oxide scale for the next stage (source: www.copper.org).

Drawing

Drawing process is for pulling the hollow tube through a series of hardened steel dies to reduce its diameter. The tube is pointed at one end to fit the next die and it is held by automatic jaws attached to a rotating, drawing machine. A tapered plug mandrel is placed inside the tube. And depending on the process used, plug mandrel can be fixed or floating. As the tube is drawn into the drawing machine, the mandrel and die act together to reduce outside diameter and wall thickness. This process is iterated until desired wall thickness is obtained (source: www.copper.org). In figure 2.5 and 2.6, the different types of drawing are shown.

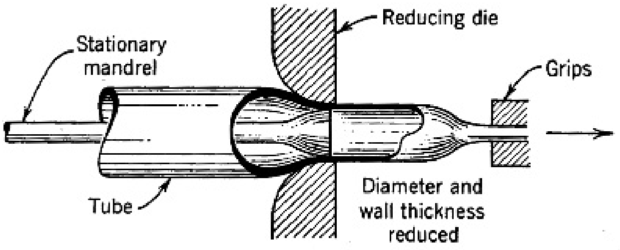

Figure 2.5 Tube drawing over fixed mandrel (Source: www.copper.org)

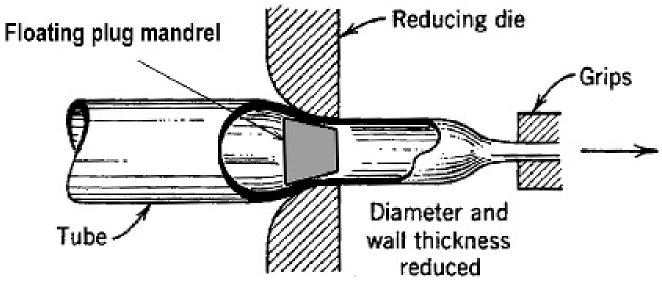

Figure 2.6 Tube drawing over a floating plug mandrel (Source: www.copper.org)

Final Steps

Now the tube is ready to be shipped. At regular intervals, the samples of the finished tubes are taken and ensured that it meets all the requirements of the ASTM B88.

2.8 Environmental aspect of copper pipe

In the US, the usage of copper in plumbing systems has risen nearly 5 percent per year since 1992, and in 1997, it reached approximately two thirds of a billion pounds. More than 90 percent of domestic plumbing systems are composed of copper. And of all copper consumed in US, copper water tube accounts for about 8 percent. 65 percent of the copper tube is derived from the recycled scrap. The plumbing pipe is never deserted to landfill. It’s known that almost all the copper pipe is recycled. For economic and technical reasons, new copper is used even though the scrap as a raw material is helpful to the environment. The scrap usually costs less. But copper market fluctuation causes the price of refined copper and that of the scrap almost the same. If the distance from a tube plant that produces scrap is far away, then the refined copper becomes the better option to avoid the additional transportation fee. Some manufacturers cannot remove impurities from scrap in their plant. Then they have no choice but to buy refined scrap. Sometimes tube makers are forced to use refined copper as the furnaces are shut down due to maintenance problems. These problems are quite frequent nowadays in the US. That’s why still refined copper is used for plumbing (source: www.copper.org).

2.9. LCA application to copper plumbing pipes

The purpose of the Life Cycle Assessment for copper plumbing pipe is to understand the impacts of it on the environment. LCA should be performed for other plumbing materials such as plastics and stainless steel as well for comparing economic effects, material performance, and customer satisfaction.

A 100 ft copper L pipe can be considered as the functional unit. Next, inventory analysis should be carried out. The flow chart for each process is constructed. As mentioned in the previous section, copper mining, milling, smelting, and copper pipe manufacturing including melting, casting, piercing, extrusion, drawing, and usage, maintenance, and disposal or recycling are listed. For each step, inputs resources, and energy consumption and product outputs involving emission to air, and other impacts water are required. However, the aforementioned processes are too diverse for different plants and countries. The standardized data are in general hard to obtain. The next step is to define the system boundaries. From CDA (Copper Development Association) statistics, it's known that 64% of the copper plumbing pipe is made from recycled copper which means 64 % do not need the processes of mining, milling, and fire-refining. The materials are directly obtained from available copper scrap by recycling. For each process, the sum of emissions and inputs are identified for the whole system. For example, the amount of energy consumed in mining, milling, smelting, and pipe manufacturing (casting, piercing, extrusion, drawing, and transporting) are added to yield the energy consumption value (Table 2.4).

With the inventory analysis, the effects on the environment are interpreted in impact assessment. As shown in Table 2.6, all the inputs and outputs are classified according to the environmental problems they result in. For instance, CO_2, CH_4, or O_2 can cause global warming and NO_x, NH_4, or P can be the culprit for nitrification. It's known that each input or output contributes to several problems. With an equivalency factor, total points for each principal environmental problem are summed. As shown in Table 2.6, energy depletion potential (EDP), global warming potential (GWP), photochemical oxidant formation (POCP) have total scores. This yields the load on the environment by each process.

Next step is valuation process. By assigning weighting factors to each of the environmental problems, the results are reduced to a different single index which is easier to interpret when comparing the environmental problems of different pipe materials. The weighting factor typically involves subjectivity and social preferences at that time.

Final step is improvement assessment. With the characterization of the process, production, consumption, and development can be recommended for better environment. After these processes, results can be combined with economic and other aspects of the manufacturing as a whole.

The LCA forms a part of the decision making process. Regulative processes within the local, state, and federal, governments require consideration of impacts on the environment. The key benefit of the LCA process is the framework for an analytical impact assessment of manufacturing process as whole.

Table2.3 Standard environmental data sheet

Process Data source:	Environmental Data sheet Date:
Inputs (data per tonne of main product)	**Outputs** (data per tonne of main product)
Raw Materials Extracted from the environment Bought in **Energy** **Transport Services (means, load, distance)** **Other inputs**	**Main products** **By-products (kg/tonne)** **Solid waste to be processed (kg/tonne)** **Fluid waste to be processed (kg/tonne)** **Environmental outputs (kg/tonne)** Emission to air Emission to water Emission to land

Table 2.4 Inventory table

Inventory table for 100ft of Copper L pipe

	Copper Mining	Grinding	Concentration	…..
Energy resource (GJ)				
Emission to air (kg)				
CO_2				
CO				
hydrocarbons				
NO_X				
SO_2				
Particles				
Liquid particles in air				
Emissions to water (kg)				
nitrogen				
phosphates				
potassium oxide				
calcium oxide				
magnesium oxide				
insecticides				
herbicides				
oil				
hexan				
Solid waste (kg)				
industrial				
high risk				

Table 2.5 Principal environmental problems

abiodic depletion potential(ADP)	measured relative to global supplies
energy depletion potential (EDP)	measured as MJ/kg or MJ/m^2
global warming potential (GWP)	measured relative to the effect of 1kg CO_2
photochemical oxidant formation(POCP)	measured relative to the effect of 1Kg ethylene
acidification potential(AP)	measured relative to the effect of 1Kg SO_2
human toxicity potential (HT)	measured as the human body weight that would be exposed to the toxicologically acceptable limit by 1kg of the substance
ecotoxicity, aquatic (ECA)	volume of water that would be polluted to a critical level by 1kg of substance
nutrification potential (NP)	measured relative to the effect of 1kg phosphate
ozone depletion potential (ODP)	measured relative to the effect of 1Kg of CFC-11

Table 2.6 Classification and characterization

Classification and Characterization for 100ft copper L pipe													
	Resources	**Emission to Air**						**Emission to water**					
	GJ	**CO_2**	**CO**	**C_XH_Y**	**NO_X**	**SO_2**	**C_6H_{14}**	**herbicide**	**insecticide**	**nitrogen**	**oil**	**PO_4^{3-}**	
Inventory Amounts	3.95	250.0	0.1	1.1	0.75	…	…	…	…	…	…	…	
		↓				…	…	…	…	…	…	…	
						…	…	…	…	…	…	…	
Equivalency Factors							…	…	…	…	…	…	…
						…	…	…	…	…	…	…	
ADP						…	…	…	…	…	…	…	
EDP	1.0					…	…	…	…	…	…	…	
GWP		1.0				…	…	…	…	…	…	…	
POCP				0.377		…	…	…	…	…	…	…	
AP						…	…	…	…	…	…	…	
HT						…	…	…	…	…	…	…	
ECA						…	…	…	…	…	…	…	
ECT						…	…	…	…	…	…	…	
NP						…	…	…	…	…	…	…	
ODP						…	…	…	…	…	…	…	

Table 2.6 Classification and characterization (cont’d)

Multiplied characterization results										**Total**
ADP										
EDP	3.95				**…**	**…**	**…**	**…**	**…**	**3.95**
GWP		250.0			**…**	**…**	**…**	**…**	**…**	**250.0**
POCP			0.407	0.541	**…**				→	**0.95**
AP					**…**	**…**	**…**	**…**	**…**	**…**
HT					**…**	**…**	**…**	**…**	**…**	**…**
ECA					**…**	**…**	**…**	**…**	**…**	**…**
ECT					**…**	**…**	**…**	**…**	**…**	**…**
NP					**…**	**…**	**…**	**…**	**…**	**…**
ODP					**…**	**…**	**…**	**…**	**…**	**…**