EU-MERCI

EU coordinated **ME**thods and procedures based on **R**eal **C**ases for the effective implementation of policies and measures supporting energy efficiency in the **I**ndustry

HORIZON 2020 Project Nr. 693845

Technical analysis –Other metals sector (NACE C24.4-24-5)

WP4: Picture of efficiency projects implemented by the
Industry sector-by-sector and process-by-process

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1 Introduction

The European non-ferrous metals industry has an economic and strategic importance greater than its employment, capital and turnover statistics indicate. For example, high-purity copper is essential for electricity generation and distribution and the use of aluminium is widespread in the construction, transportation and utilities industries.

All non-ferrous metals have their own individual properties and applications. In several cases however, such as in copper and aluminium manufacturing, alloys are used in more applications than pure metals as they can be designed to have a specific strength or toughness to meet the requirements of particular applications.

Metals are inherently recyclable and can be recycled time after time without losing any of their properties. They this make a significant contribution to their sustainable development. It is normally not possible to distinguish between refined metal that has been produced from primary raw materials and metal that has been produced from secondary raw materials.

Manufacture of non-ferrous metals make up the following classes:

- Copper and its alloys
- Aluminium
- Lead and tin
- Zinc and cadmium
- Precious metals
- Ferro-alloys
- Nickel and cobalt
- Carbon and graphite

1.1 Scope of the industry

The output of the industry is derived from a variety of primary and secondary raw materials. Primary raw materials are derived from ores that are mined and further treated, for example by washing and jigging to reduce waste material before they are metallurgically processed to produce crude metal. The treatment of ores is carried out close to the mines as, increasingly is metal production. Secondary raw materials are indigenous scrap and residues.

Most metal concentrates are imported into Europe from a variety of sources worldwide. The use of indigenous secondary raw materials is critical in the non-ferrous industry and recycling facilitates a much more efficient process than primary production.

For example, in the copper sector, secondary raw materials account for the production of about 40% of EU copper, but in some cases such as brass rods, the product is made entirely from recycled copper and brass. When copper cathodes are produced from recycled materials in the EU there are savings of approximately 650,000t of CO_2 compared to production from primary sources because specific direct emissions of secondary smelters are four times lower than those of primary smelters.

In the aluminium sector, the production and refining of secondary aluminium is also much less demanding in terms of energy, accounting for a consumption per kg of Al produced of about 5% of the energy needed to produce primary aluminium.

1.1.1 The structure of the industry

The structure of the industry varies by metal. There are no companies that produce all or even a majority of non-ferrous metals, although there are a few pan-European companies producing several metals. The size of companies producing non-ferrous metals and non-ferrous metal alloys in Europe varies from a few employing more than 5000 people to a large number having between 50 and 200 employees.

The table shows the global estimated energy consumption by each non-ferrous metal in 2004.

Table 1: Energy consumption of non-ferrous metals sector.

Description	**Production** [Mt/yr]	**Final Energy Use** [GJ/t]	**Primary Energy Intensity** [GJ/t]	**Primary Energy Use** [PJ/yr]
Aluminium	30.2	100	175	5,285
Copper	13.8	N/A	93	1,283
Chromium	17	N/A	50	850
Manganese	11	N/A	50	550
Nickel	1.4	N/A	160	224
Zinc	8.5	N/A	50	425
Tin	0.264	N/A	50	13
Lead	2.95	N/A	20	59
Gold	0.0025	N/A	52,000	130
Silver	0.020	N/A	2,900	58
Total	-	-	-	8,877

From the table above and the data reported in par. **Errore. L'origine riferimento non è stata trovata.**, it is clear that the copper and aluminium industries dominate the European non-ferrous metals market and the share of global non-ferrous metals energy consumption. Therefore, this report will focus mostly on the copper and aluminium production process.

1.2 Environmental Performance

The recycling rate of the industry is very high. Metals are often produced at lower energy costs using the recycling route. For copper for example, secondary smelting compared to primary smelting emits 4 times less carbon dioxide, consumes 3 times less electricity and 2.5 times less fuel for combustion. Additional efforts to recycle low-quality, metal-bearing residues are however required to protect the environment and improve energy efficiency even further.

1.3 Outline of process analysis

This report will begin by explaining the general processes that can be used in the production of all non-ferrous metals and then explore in more detail the specific processes and energy usage in the production of copper and aluminium more specifically.

2 Process Analysis

2.1 General processes – raw material preparation

2.1.1 Thawing

Thawing is performed to allow frozen material to be handled. This occurs, for instance, when ores or concentrates or solid fossil fuels such as coal are discharged from a train or ship in the wintertime. Thawing can be achieved by using steam jets in order to just melt the ice to enable unloading of the raw material.

2.1.2 Drying

Drying processes are used to produce a raw material that is suitable for the main production process. Rotary, steam coil and other indirect dryers are used and their economics, availability, reliability and source of energy used need to be taken into consideration.

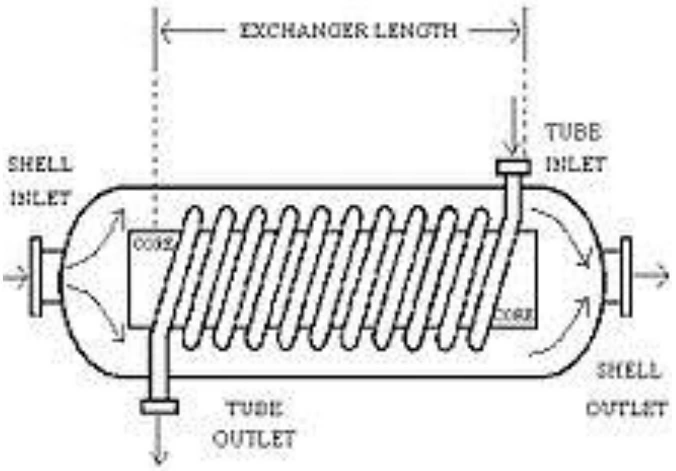

Figure 1: A simple representation of a heat exchanger coil.

Drying is usually achieved by the application of direct heat from a burner or by steam jets, or indirectly using steam or hot air in heat exchanger coils (Figure 1). The heat generated from pyrometallurgical processes, e.g. anode furnaces, is also often used for this purpose, as well as the CO-rich exhaust gas that can be burnt to dry the raw material. Rotary kilns and fluidised bed dryers are used.

2.1.3 Crushing, size reduction and screening

Crushing, size reduction and screening are practised to reduce the size of products, residues or raw material so that it is suitable for sale or further processing. Many types of crusher are used including cone crushers and ball crushers. Wet or dry materials are crushed and a blending stage can be included.

Granulation is used to produce small particles of slag, which are suitable as shot blasting material, road fill or a material that can be reprocessed to recover the metal content. Molten slag is cast into a water bath or poured through a stream of water.

2.1.4 Battery breaking

Battery breaking is used to recover lead, nickel, cadmium and other materials from batteries. For lead-acid batteries, hammer mills are used to break the battery cases to liberate lead (as grids) and lead compounds (as paste) and allow the recovery of the plastic case material (mainly polypropylene). The electrolyte is also removed and treated or used.

2.1.5 Blending

Blending is performed to mix ores or concentrates of varying quality and to combine fluxes or reducing agents with the ore to produce a stable feed to the main process. Blending can be achieved in proprietary blending equipment, in the grinding stage, or during the conveying, drying and storage stages. Accurate blends are produced using bedding plants, loss-in-weight dosing systems, belt weighers or by volume from the loading equipment.

2.1.6 Briquetting, pelletising and other agglomeration methods

Many techniques are used to treat concentrates, flue-dusts and other secondary material and they include the baling of wire or small scrap, compressing briquettes of material and extruding or rolling pastes to produce even-sized balls of material. Coating and binding agents are used for this purpose to reduce dust development in subsequent process steps.

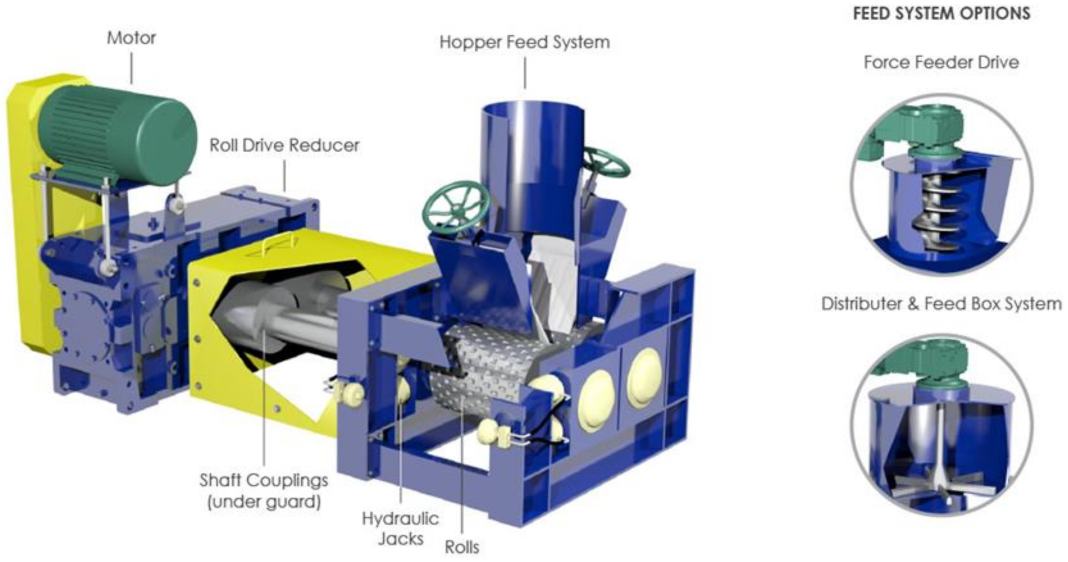

Figure 2: Mechanical construction of a briquetter.

Briquettes and pellets which contain a mixture of fine ore or concentrate, recycled dust and additional material such as reducing agents are often produced to ensure efficient smelting conditions. After adding binders or water, the mixture is fed into a press (Figure 2) to produce a pillow-shaped briquette or into a rotary pelletising drum, pelletising disc or mixing machine to produce pellets.

2.1.7 Sintering and calcination

These processes are used to increase the size of the raw material or the chemical composition so that it is suitable for further processing. Agglomeration and sintering allow a more even gas flow through a furnace bed and reduce dust formation, gas volume and diffuse emissions.

Sintering and calcining (Figure 3) are also used for this purpose and additionally are used to adjust the chemical form of the mix or to convert any sulphur present, e.g. the calcination of dolomite into dolime in the production of magnesium. The main binding mechanism in ore sintering is achieved by bringing the ore up to a temperature where the gangue minerals start to melt, whereby individual particles are fused together in a matrix of molten slag.

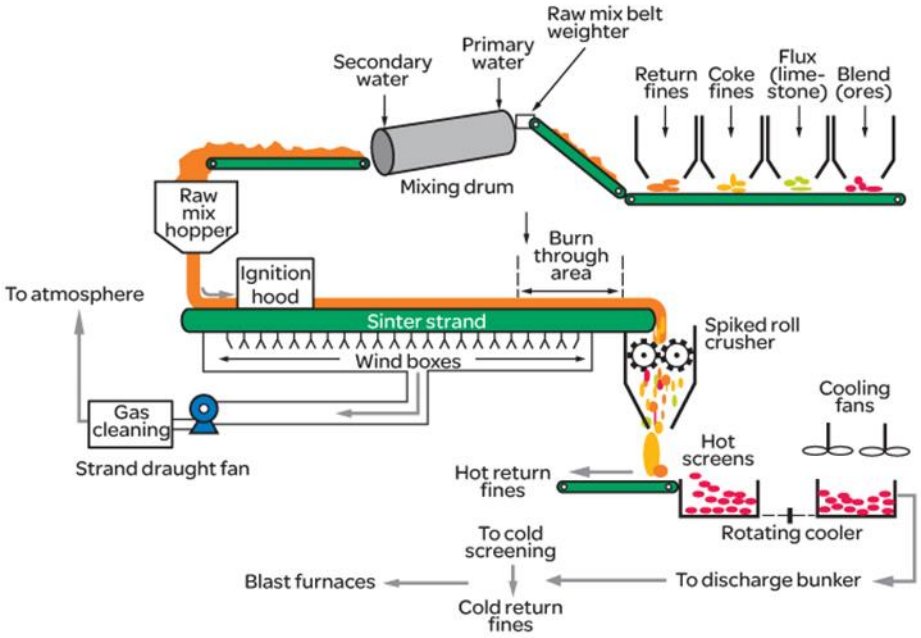

Figure 3: Simplified diagram of a sinter plant.

2.1.8 Fuming processes

These processes are used to fume volatile metals such as lead or zinc from a substrate. The processes use high temperatures and a source of carbon to produce an inert slag by fuming or volatilising metals from the material. This allows the metals to be recovered, usually as an oxide, for further processing. Waelz kilns, Herreshoff and slag-fuming furnaces are used.

2.1.9 De-coating and de-oiling

De-coating and de-oiling operations are usually performed on secondary raw materials to reduce the organic content of the feed to some main processes. Washing and pyrolysis processes are used. Centrifuging can recover oil and reduce the load on the thermal system. Major variations in organic content can cause inefficient combustion in some furnaces and produce high volumes of combustion gases that contain residual organic compounds.

The removal of oil and some coatings is achieved in a specially designed furnace such as a swarf dryer. In most cases, a rotary furnace (Figure 4) is used at a low temperature to volatilise oil and water. Mechanical stripping is also used frequently to remove insulation from cables and coatings from other materials. Some processes use cryogenic techniques to make the coating brittle and therefore easier to remove.

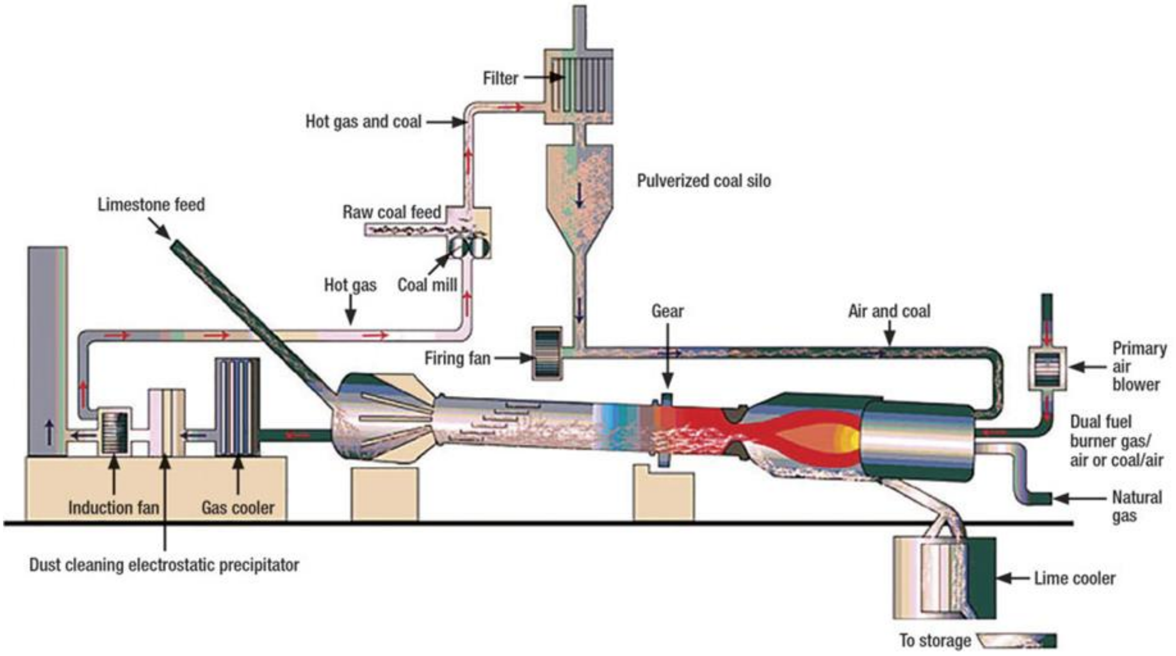

Figure 4: Diagram of a rotary furnace.

2.1.10 Incineration and pyrolysis

Incineration and pyrolysis processes are normally used to treat photographic film, sweepings, catalysts and other materials to concentrate the precious metals content or to recover nickel. They are also used to pre-treat catalysts to remove the organic content before further treatment. These processes are usually carried out at low temperatures to prevent the carryover of the metals.

2.1.11 Leaching and washing procedures

Leaching or washing procedures are used to concentrate metal from ores or concentrates in a liquid phase. Washing is used to remove impurities such as alkali and alkaline earth compounds from some concentrates and secondary raw materials before further processing. Washing is also used to reduce the content of cadmium, chloride and sulphate, etc. in residues to meet the processes requirements or to recover them.

2.1.12 Separation techniques

These processes are used to remove impurities from raw materials prior to their use.

In non-ferrous metals plants, separation techniques (Figure 5) are more frequently used for secondary raw materials and the most common is magnetic separation to remove items of iron. Manual and mechanical separation techniques are used to pre-treat waste streams such as the removal of batteries, mercury contacts, etc. from electronic equipment, or the separation of the car catalyst from the steel casing. The separation makes it possible to recover more metals in dedicated processes.

2.1.13 Transfer and charging systems

These systems are used to convey the raw materials between pre-treatment stages and then into the main process. Techniques similar to those used for raw materials are used and similar problems of dust production, containment and extraction exist. Pneumatic, dense air and air slide systems are also used and can even out variations in feed quality. Collected material is reused.

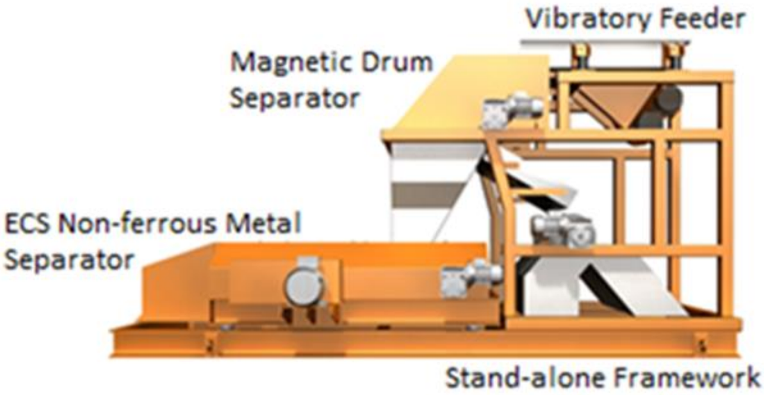

Figure 5: An example of an Eddy Current Separator.

3 Copper and its alloys

3.1 Overview

Copper has been used for many centuries due to its very high thermal and electrical conductivity and its resistance to corrosion. Copper is frequently alloyed with Zn, Sn, Ni, Al and other metals to make a large array of brasses and bronzes. Copper production is based on grade A copper cathodes, i.e. 99.95% Cu.

3.1.1 Sources

Refined copper is produced from primary and secondary raw materials by a relatively small number of copper refineries; their product is copper cathode. This is melted, alloyed and further processed to produce rods, profiles, wires, sheets, strips, tubes, etc. This step may be integrated with the refinery but is frequently carried out at another site.

With about 835,000 tonnes of copper extracted from domestic ores in 2011, the EU-28 countries account for around 5% of the total worldwide copper mine output.

3.1.2 Production and use

The products of the refineries are the major raw materials for the manufacturers of semi-fabricated products. With an output twice that of EU refinery output, the EU-28 semis manufacturers directly use a significant amount of scrap in the range of one million tonnes per year. It is estimated that around 60% of their raw materials come from primary sources, the remaining 40% from the direct use of scrap and other secondary materials.

The 2005 output of the copper and copper alloy semis industry in the EU-27 exceeded 5.2 million tonnes (about 4.8 million tonnes copper equivalent). This represented more than one quarter of global production.

The electrical wire rod sector accounts for around half of semis production. Some 20 companies, employing around 3,000 people in total, are involved in this sector.

A simplified flowchart of the production processes involved in copper production is shown below (Figure 6). Each stage of the process will then be described and explained in more detail.

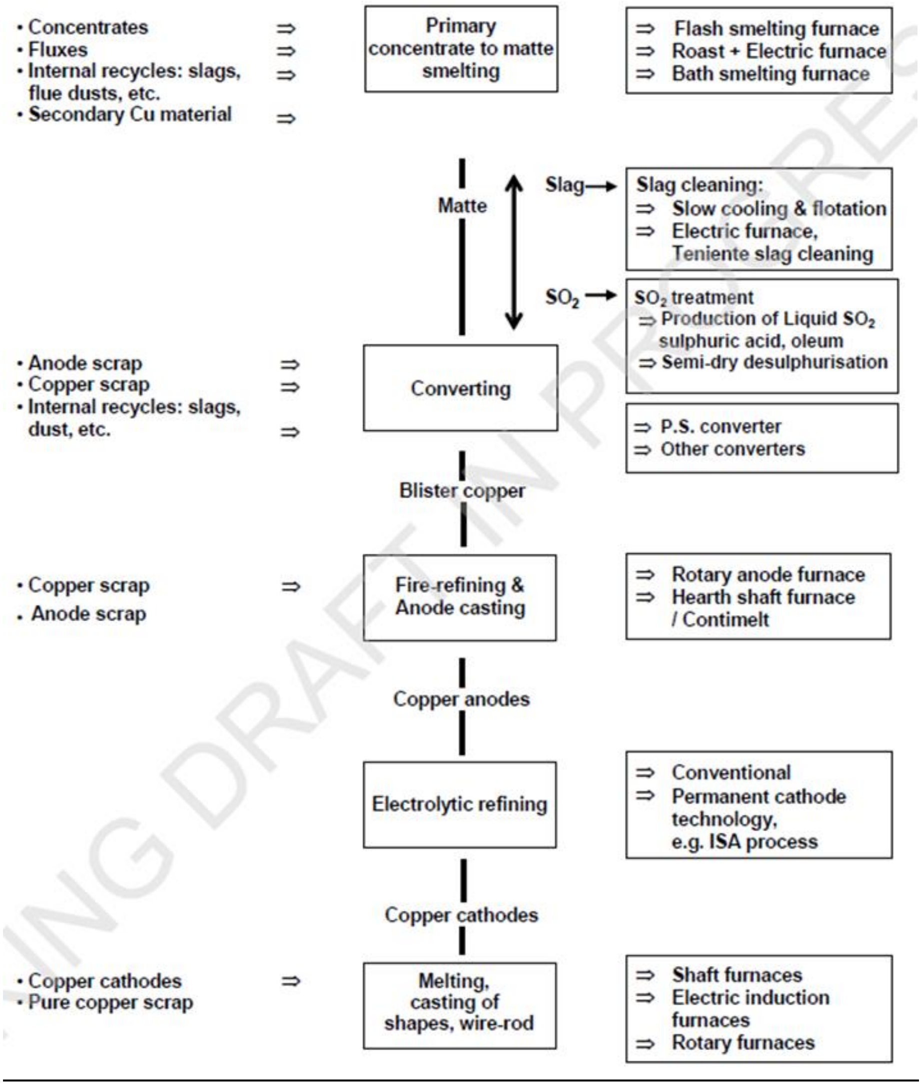

Figure 6: A representation of the overall process to produce copper from primary raw materials.

Primary copper can be produced by pyrometallurgical or hydrometallurgical processes. Approximately 20% of primary copper is produced by the direct leaching of ores (hydrometallurgical route). Nowadays, sulphidic concentrates (15–45% Cu) are the most important raw materials for the pyrometallurgical primary copper route, with a share of more than 85%. To a small extent, oxidic/sulphidic mixed ores and, more seldom, bituminous ores are processed.

3.2 Pyrometallurgical route

The pyrometallurgical route entails a number of steps, depending on the concentrate used. The majority of concentrates are sulphidic and the stages involved are roasting, smelting, converting, refining and electrorefining.

3.2.1 Roasting and smelting

There are two types of dryers used for drying copper concentrates:

- Hot gas rotary dryers heated by the off-gases from combustion.
- Steam-heated coil dryers.

The rotary dryer is a rotating drum. The hot gas produced by the combustion of natural gas is placed in contact with the wet concentrate and the contained water is transferred to the gas.

The steam dryers are indirectly heated via steam coils. The throughput depends on the steam pressure; by increasing the pressure to 18–20 bar the capacity can be raised. A small amount of carrier air is introduced to pick up the water of the concentrate.

Roasting and smelting are usually carried out simultaneously in a single furnace at high temperatures to produce a melt that can be separated into a matte (copper sulphide with some iron sulphide) and a slag rich in iron and silica. A fluxing agent that contains silica and, if required, lime (CaO) is usually added to the melt to aid the formation of the slag.

For copper concentrate with a low sulphur content and a high organic carbon content, the smelting may be carried out in a shaft/blast furnace (Figure 7).

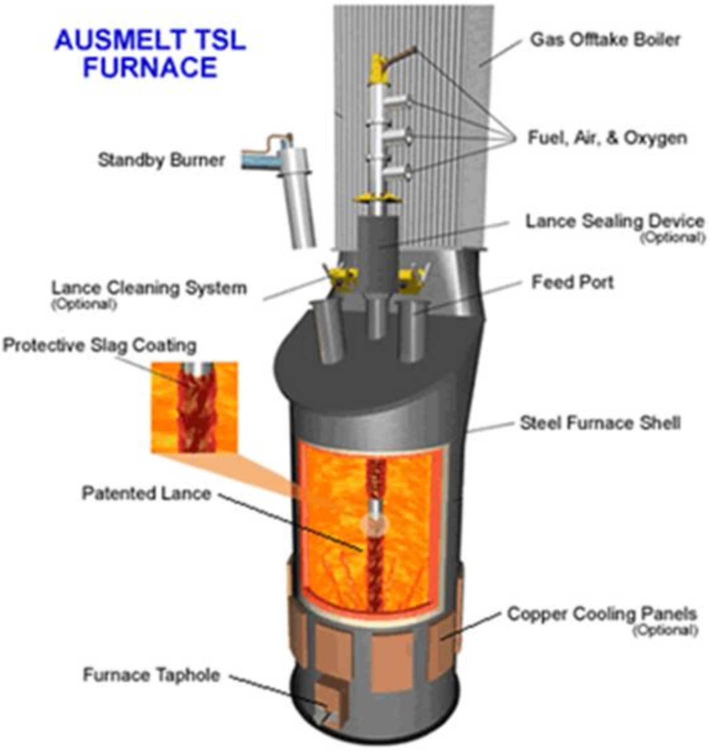

Figure 7: An example of a Russian copper shaft furnace.

In the case of very impure copper concentrates, partial roasting converts the complex sulphides of iron and copper in the concentrate into simple sulphides, by heating the ore or concentrate under oxidising conditions.

There are two basic smelting processes in use: bath smelting and flash smelting. The flash smelting process uses oxygen enrichment to produce an autothermal (autogenic) or nearly autothermal operation. Bath smelting processes generally use a lower degree of oxygen enrichment.

Bath smelting is carried out in a number of proprietary furnaces such as the reverberatory, shaft (or blast), electric, Ausmelt/ISASMELT, Noranda, Mitsubishi, El Teniente, Baiyin and Vanyukov furnaces.

Flash smelting is carried out in either the Outotec or INCO flash smelters. The Outotec and cyclone processes use oxygen enrichment and the INCO process uses pure oxygen. Flash smelting relies on the oxidation and smelting of dry concentrates in airborne particles.

3.2.2 Converting

Three types of converter processes are used during primary processes; two are matte conversion processes and one is an alloy conversion. The matte conversion processes are the conventional batch process, which is most commonly used and the continuous converting process.

3.2.3 Batch matte converting process

The batch converting process comprises two stages. It is carried out by blowing an air/oxygen mixture through the matte recovered from the smelting operation. A cylindrical bath furnace is most commonly used and flux additions are added. In the first stage, iron and part of the sulphur are oxidised and slag and sulphur dioxide gas are formed; the slag is skimmed off periodically and is further processed to recover copper. In the second stage, i.e. the copper blow, the copper sulphide is oxidised to blister copper (98.5% Cu) and more sulphur dioxide gas is formed.

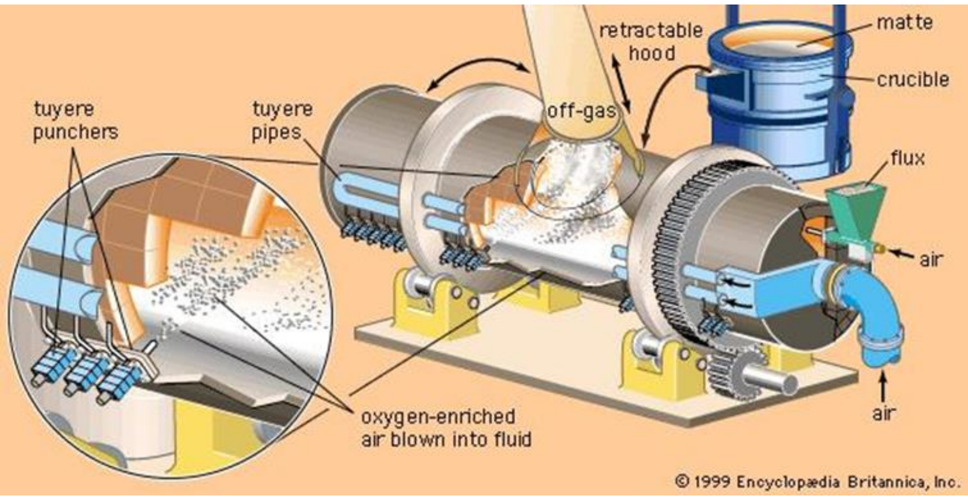

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Figure 8: A side-blown copper-nickel matte converter.

3.2.4 Continuous matte converting process

The continuous converting processes that are in industrial use are the Kennecott-Outotec flash converting furnace, the Mitsubishi furnace (which forms part of the integrated Mitsubishi process) and the Noranda converter.

The Mitsubishi and the Noranda furnaces receive molten feed for conversion. In contrast, the Kennecott-Outotec process is as follows: matte from a smelting furnace is first granulated in water, crushed and dried (see Figure 9 below). The material is then blended with slagging agents and fed into the concentrate burner of a specific flash furnace using an oxygen-rich atmosphere; conversion takes place in the airborne particles.

There are significant differences between batch-wise and continuous converter concepts in operation and in sulphur dioxide output variations throughout the converting cycles. There are also variations in the ease of collecting fumes during charging and in the ability to melt scrap anodes.

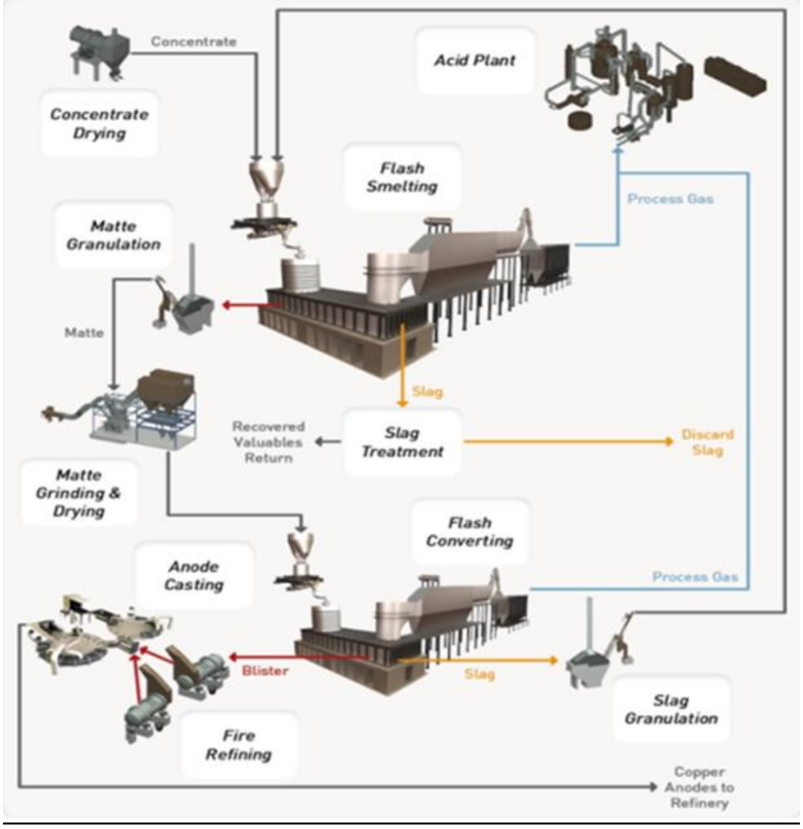

Figure 9: A representation of the Kennecott-Outotec process.

3.2.5 Alloy converting process

Alloy converting is a batch process in which alloy from the electric furnace serving a direct to blister flash furnace is treated. One converter cycle lasts about 8 hours. About 5–6 tonnes of limestone per batch is added to help the slagging of the oxidised iron and lead in the first converter stage.

3.2.6 Refining (fire-refining)

Fire refining is a further purification step applied to the crude metal (blister copper) produced by the conversion stage. The refining step involves the addition of air and then a reducing agent (e.g. hydrocarbons) to reduce any oxide present.

Fire refining is achieved by first blowing air through the molten metal to oxidise impurities and to remove final traces of sulphur (oxidation stage). A small amount of slag is produced at this stage that needs to be removed prior to the next stage. In the next stage (reduction or 'poling'), a source of reducing agent, such as natural gas or propane, is then added to partially remove the oxygen that is dissolved in the liquid copper. Ammonia may also be used as a reducing agent, but has been reported to increase NO_x levels. Several installations use an afterburner to treat the gases during the poling stage.

3.2.7 Electrolytic refining

An electrolytic cell (Figure 10) is used and it consists of a cast copper anode and a cathode placed in an electrolyte that contains copper sulphate and sulphuric acid. The cathode is either a thin blank of pure copper (starter sheet) or a stainless steel former sheet (permanent cathode plate). At a high current density and low voltage, copper ions are dissolved from the impure anode and pass into solution from where they are deposited onto the cathode. Copper is removed from the anode to the extent that the remaining anode is still mechanically strong enough to prevent a collapse.

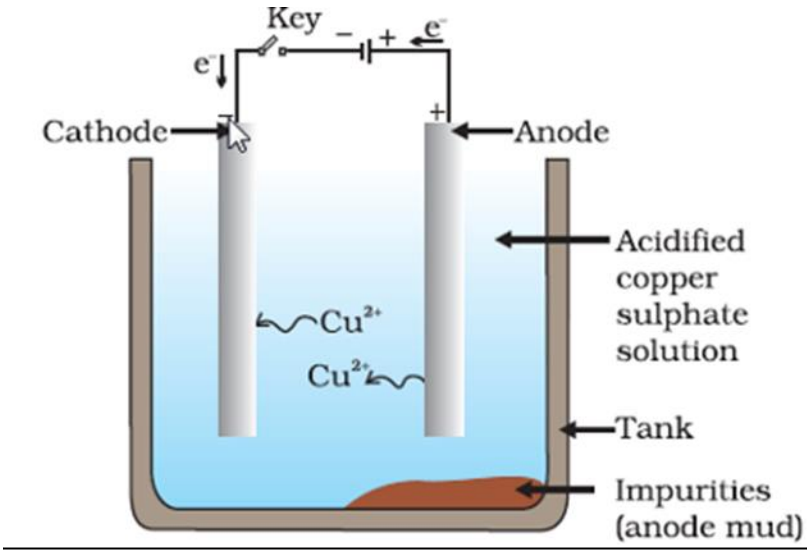

Figure 10: simple representation of an electrolytic refining cell.

3.2.8 Treatment of copper rich slags

The slags produced from primary smelting with high grates matte and converting stages are rich in copper and are subjected to a number of slag treatment processes. One process is the use of an electric furnace for the reaction of slag with carbon in the form of coke breeze or with the electrodes themselves and for the settling of copper matte that is formed, to produce an inert slag.

Alternatively, flotation processes are used after the slag has been slow-cooled, crushed and milled and the flotation concentrate obtained is a copper-rich portion which is returned to the smelter.

3.3 The hydrometallurgical route

This process is usually applied to oxide or mixed oxide/sulphide ores at mine sites where there is sufficient space to form the leaching and treatment areas. The process (Figure 11) is particularly useful for ores that are difficult to concentrate by conventional means and which do not contain precious metals. The hydrometallurgical route involves the crushing of the ore followed by leaching using sulphuric acid, sometimes in the presence of biological species, using heap, vat or agitation processes. The liquor produced from leaching is then clarified and purified and concentrated by solvent extraction. The copper in the organic solution is then stripped by sulphuric acid. The stripped solution, containing mainly copper sulphate, is sent to the electro-winning stage.

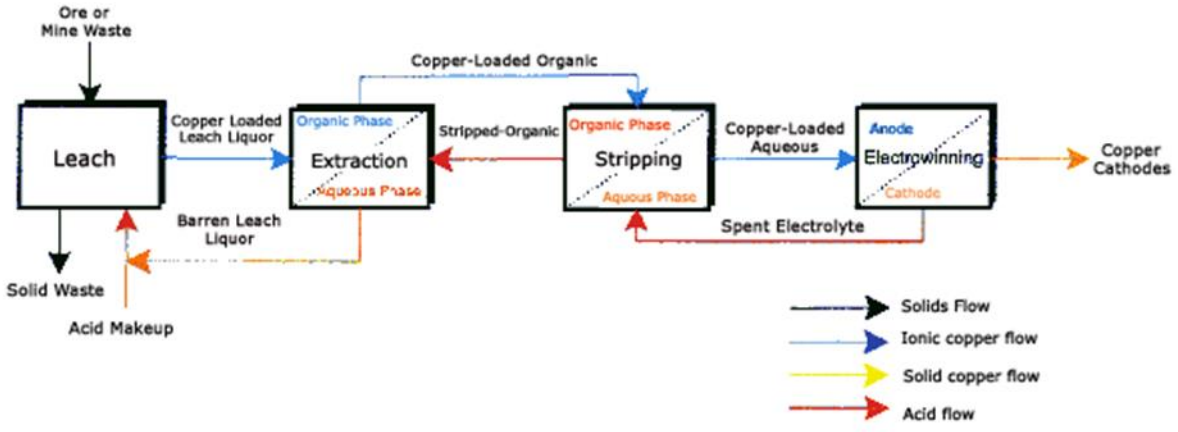

Figure 11: Simplified representation of the hydrometallurgical copper production process.

3.4 Secondary copper production

Secondary copper is produced by pyrometallurgical processes. The process stages used depend on the copper content of the secondary raw material, its size distribution and the other constituents. As in primary copper, the various stages are used to remove these constituents and to recover metals to the greatest possible extent from the residues that are produced.

3.4.1 Secondary copper smelting stage

A number of furnaces such as the blast, Mini Smelter, top-blown rotary furnaces (TBRC), sealed submerged arc electric furnace, Ausmelt/ISASMELT furnace (KRS or Kayser recycling system), reverberatory and rotary furnaces are used for low and medium-grade material.

The type of furnace and the process steps used depend on the copper content of the secondary raw material, its size and other constituents. The smelting and refining of secondary copper is therefore complex and the type of secondary material which can be processed is dependent on the particular facilities and furnaces available.

3.4.2 Converting, fire-refining and electro-refining

The converting and refining furnaces used are the same as those used for primary copper production and the slag treatment systems and electro-refining processes are also the same. The main difference is that converters used for secondary production treat metal and not matte. These furnaces usually use natural gas as fuel and coke as the reducing agent for melting and to make up process heat deficits, while in the primary converters the matte provides the necessary process heat.

3.4.3 Melting, casting of shapes and wire-rod

Copper alloys such as bronzes and brasses are also used as secondary raw materials in a number of processes. If impure or mixed with other alloys, they are processed in the secondary smelting and refining circuits.

The pure alloy is used directly for semis fabrication. Induction furnaces are used to melt the clean material followed by casting into shapes suited for the further fabrication step.

3.5 Wire rod production

Wire rod is manufactured from high purity electro-refined copper cathodes, thus ensuring that trace impurities, which may affect conductivity, annealability and hot shortness, are minimised.

3.5.1 Southwire process

An example of the Southwire process is given below (Figure 12).

The feed materials are melted by natural gas, propane or similarly fired burners arranged in rows around the furnace shell. The fuel is burnt under closely controlled combustion conditions to maintain a slightly reducing atmosphere (less than 0.5% to 1.5% of CO or H_2) in the areas where the gases are in contact with the copper, to minimise the oxygen content of the copper.

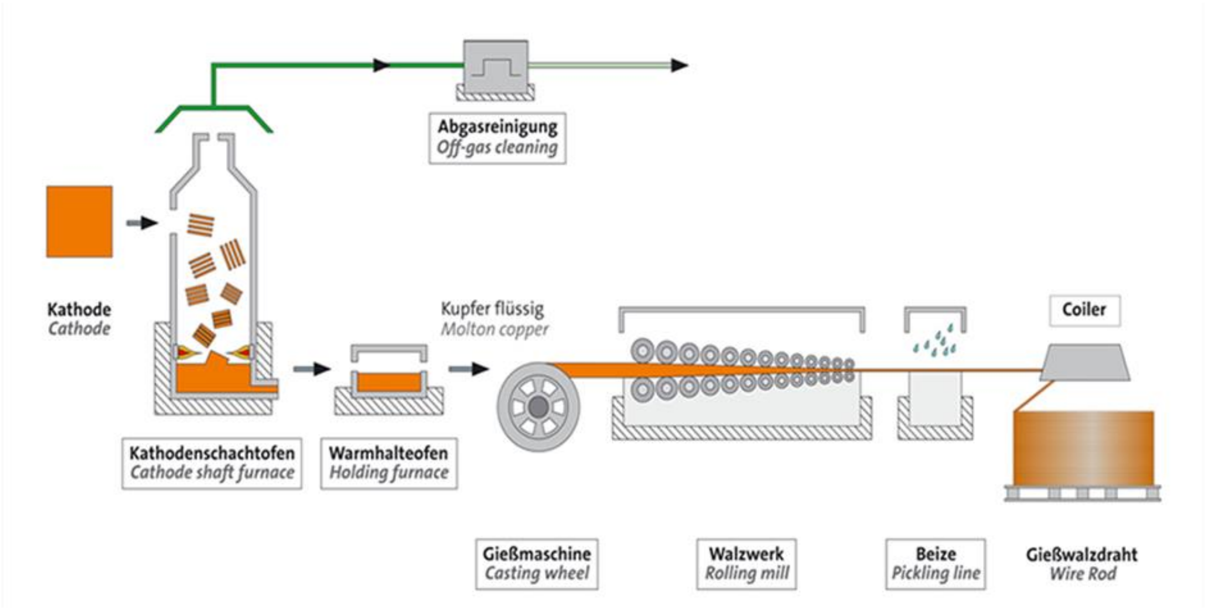

Figure 12: A representation of the Southwire process.

3.5.2 Contirod process

A shaft furnace is used to melt copper. Molten copper from the furnace flows via a launder equipped with siphons into a rotating, gas-heated holding furnace. The copper then flows to the pouring funnel, which automatically controls the feeding rates to the caster.

3.5.3 Properzi and Secor processes

The continuous Properzi and Secor processes are similar to the Southwire process with variations in casting geometry. The features described for the Southwire process are also valid for these two copper wire rod fabrication systems.

3.5.4 Upcast process

Copper is melted in a channel induction furnace. The melt is transferred in batches into an induction holding furnace. For small production capacities, a single combined melting-holding furnace may be sufficient.

3.5.5 Dip-forming process

The preheated feed material is discharged into a channel induction melting furnace. Copper passes to the holding furnace and the crucible that is attached to the holding furnace. A mother rod, 12.5 mm in diameter, is drawn through an inlet die at the base of the crucible. Drawing the core wire through the metal pool and controlling the final diameter through the upper die increases the diameter. The cast rod is directed via dancers to a three-stand rolling mill producing 8.0 mm and 12.5 mm rods.

3.6 Production of semi-finished products of copper and copper alloys

Copper and copper alloys are melted continuously or in batches and cast for the production of shapes suited to the further fabrication step. A diagram showing the semi-finished product fabrication process is shown below (Figure 13).

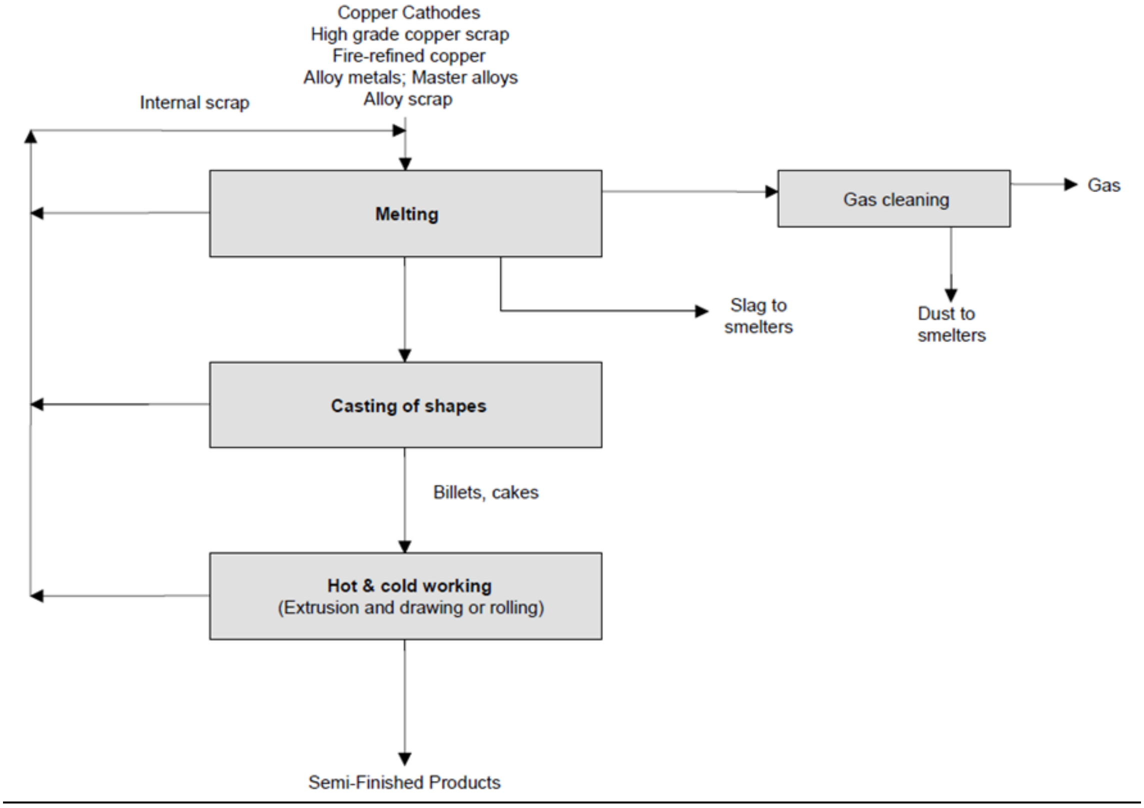

Figure 13: A representation of the semi-finished products of copper production.

3.6.1 Melting processes

Copper or copper alloys can be melted in batches in an electric or induction furnace (crucible or channel type). When high melting rates are required, copper is also melted continuously in a shaft furnace. Crucible or reverberatory furnaces are also used for melting and fire-refining copper.

3.6.2 Casting

Normally, molten metal from the furnace or holding section can be cast continuously or in batches. Continuous casting uses either vertical or horizontal modes while discontinuous casting normally uses the vertical mode. Upcast techniques are also used. Billets and cakes/slabs are produced and are processed further. A diagram showing the principle of continuous or semi-continuous casting is shown below (Figure 14).

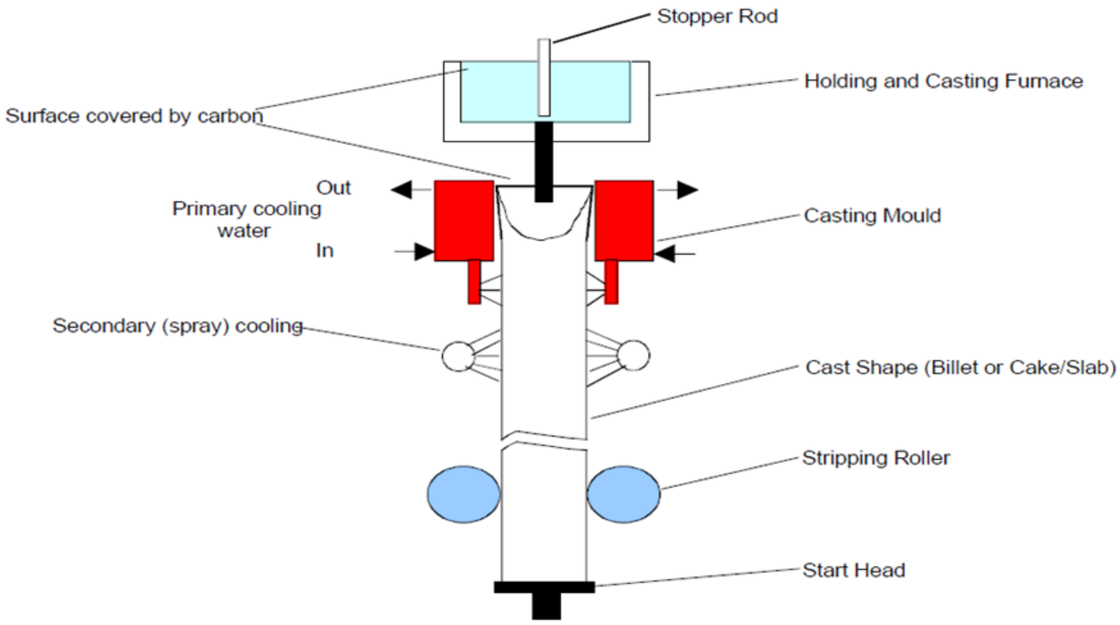

Figure 14: A representation of the continuous or semi-continuous casting process.

3.7 Hot and cold working (extrusion and drawing/rolling) – Fabrication of tubes, sections and rods

The fabrication process lines can be subdivided into two product groups, with each product group following the same process steps:

- Copper tubes in straight length and coils
- Copper (alloy) tubes, as well as copper and copper alloy rods, bars, wires and sections

In both cases, the starting materials for the fabrication process are copper or copper alloy billets. The billets in the first stage are electrically or indirectly preheated by gas-fired units and then pressed in unfinished tubes using hydraulically operated extrusion. For the fabrication of copper tubes, depending of the type of product to be fabricated, different processes are industrially applied:

- Tube extrusion followed by multi-step drawing to size
- Tube extrusion followed by breakdown rolling followed by several steps of drawing to size
- Hot piercing mill followed by breakdown rolling and drawing to size

For the fabrication of copper alloy rods, bars, wires and sections, the processes that are normally used are material extruding in coils or straight lengths followed by cleaning and pickling, drawing to size (using draw-benches or continuous drawing machines), heat treatment for certain alloys and straightening and sawing.

3.8 Production of copper and copper alloy ingots

Ingots of copper or its alloys are produced for the foundry industry using a fixed mould casting process. A wide variety of alloys are produced with other metals such as nickel, tin, zinc, aluminium, etc.

The production of ingots requires the production of an accurate alloy composition. This is achieved at the raw material reception and storage stage by segregation and sorting. Old scrap is normally stored in open bays so that the different alloys can be blended to produce the final alloy. Pre-blending is an important factor to reduce the time taken in preparing the melt, which minimises the energy used and reduces the reliance on expensive master alloys.

Rotary furnaces are normally used for dirtier scrap and oxy-fuel burners are also used frequently. Fluxes can be added to separate unwanted components, in particular iron and the slag is tapped separately from the metal.

The furnace melt is sampled and analysed and final alloy adjustments are made. Metal is then tapped in to covered launders that feed a chain of ingot moulds. The moulds are normally treated with a mineral to prevent sticking and oil fumes are produced.

3.8.1 Master alloys

The furnace charge is normally pre-adjusted to suit the alloy to be used but molten metal can be transferred to a ladle or holding furnace so that the alloy composition can be finely adjusted before casting. Master alloys such as CuP, CuNi, CuZnPb, CuBe, etc. are used for this purpose. These master alloys are produced in similar furnaces to those described above; the nature of fumes and dust from the production of master alloys influences the process control and the collection and abatement systems that are used.

3.8.2 Pickling operations

Wire, tube, strip and some other materials are pickled to produce a bright finish before packing or, in the case of copper wire, to remove oxide from the surface prior to wire drawing. Sulphuric acid solutions are used and sometimes a mixture of dilute sulphuric and nitric acids are used.

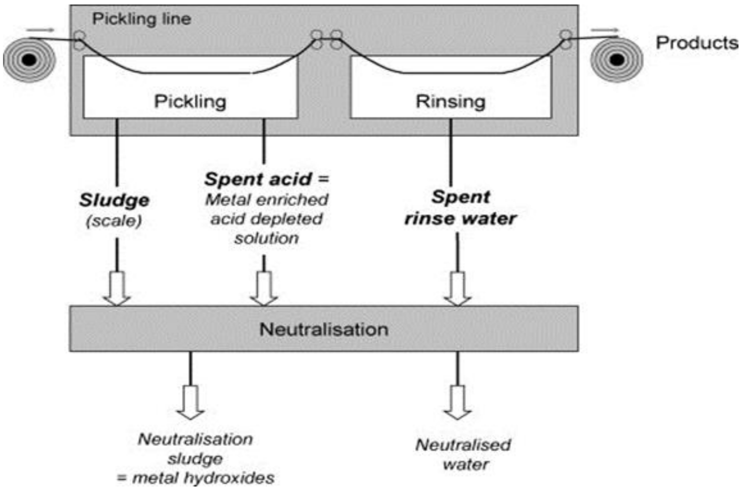

Figure 15: Pickling process for metals.

3.8.3 Non-acid pickling

This process operates in a sealed circuit. Rods can be pickled in an in-line system that consists of a compartmentalised horizontal steel pipe. A 2.5% to 5% solution of isopropanol alcohol (IPA) in water is used. The process of converting the cuprous oxide scale with alcohol to form copper (partly left on the rod) is known as the Burns process.

After pickling, the rod is dried using compressed air. Then it is given a coating of wax, applied as a fine spray with a 4% wax emulsion which prevents oxidation of the surface of the rod.

3.8.4 Acid pickling – copper wire rod

Acid pickling of copper wire rod uses a compartmentalised horizontal stainless steel pipe. In a first stage, the rod is pickled with diluted sulphuric acid; then the residual acid is washed in several stages from the rod surface by water sprays, followed by drying using compressed air and then coating by wax.

3.8.5 Acid pickling – semis of copper and copper alloys

The surface pickling of sheets and strips is usually performed with sulphuric acid (8–10%) but for some special alloys mixtures of sulphuric and nitric acids are used in continuous lines or automatic systems. Gas cleaning is used to remove nitric acid fumes. The acid is changed from time to time in order to ensure that surface quality is not affected.

3.9 General processes – water and waste management

These processes are steps that can be applied not just to copper but also to other non-ferrous metals.

3.9.1 Dry abatement techniques

Wet air pollution control equipment is gradually being replaced by dry control techniques. Dry abatement techniques like fabric filters have the advantage that no sludge or waste water are treated and the collected dust can often be recycled directly back into the main process and so the cross-media issues are therefore reduced in comparison to wet systems.

3.9.2 Wet air cleaning techniques

There are certain cases when wet air cleaning techniques, e.g. wet scrubbers or wet electrostatic precipitators, need to be applied. These are used especially when other abatement systems are not suitable, where there is a risk of explosion or combustion from flammable particles and if gaseous substances (for example, sulphur dioxide or trioxide) as well as particles have to be removed from the off-gas stream.

3.9.3 Neutralisation and sedimentation

Liquid effluent generally requires further treatment, for instance neutralisation and/or sedimentation for solid-liquid separation.

3.9.4 Weak acid treatment

Weak acid produced in wet electrostatic precipitators can be treated in a number of ways:

- By concentration and then decomposition in the smelting furnace, when SO_2 can be recovered in the acid plant;
- The treated liquid can normally be sent back to the wet cleaning system, but a bleed is required to control the composition of the liquor;
- Weak acid from these processes can also be reused in other processes if they are available.

3.9.5 Mercury removal

The mercury removal step involves a gas-liquid contact tank with a solution of mercury chloride ($HgCl_2$). This mercury chloride reacts with metallic mercury from the gas to form a solid Hg_2Cl_2 precipitate (calomel). The precipitated slurry is removed and oxidised with Cl_2 to form the $HgCl_2$ washing solution. Some of the slurry is dewatered by a filter press and sold as Hg_2Cl_2 for mercury recovery or disposed of as a special waste.

3.9.6 Granulation of matt, slag and produced metal

During the production of non-ferrous metals, the matte, slag and the produced metal will be tapped off from the furnaces. The materials can be granulated separately (Figure 16) by pouring them into water, using a high-pressure water jet or other quench systems to form evenly-sized particles. The granulated metal can then be sold as metal shot. The granulated slag may be used for other purposes and granulated matte can be used in a converter stage.

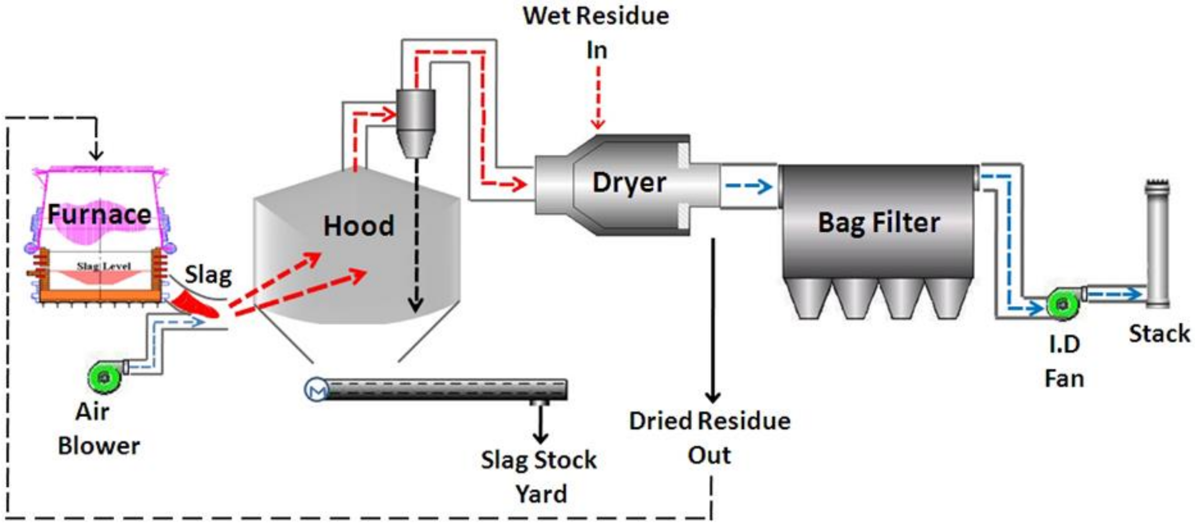

Figure 16: Representation of the wet slag granulation process.

3.9.7 Cooling water

Cooling water is used on a large scale for the different cooling requirements in metal-producing industries.

Non-contact cooling water is used for cooling furnaces, furnace hoods, casting machines, etc. Depending on the location of the plant, cooling can be achieved by a once-through system or a recirculation system with evaporative cooling towers.

Direct-contact cooling is used during some casting operations.

The amount of heat emissions and maximum discharge temperatures depend on local conditions. Specifically, the impact on the aquatic environment has to be considered on a case-by-case basis.

3.10 Residue management

The production of non-ferrous metals from primary and secondary raw material is related to the potential generation of a wide variety of by-products, intermediate products and wastes. The focus should always be on the minimisation of waste by optimising the process and by utilising residues and wastes as far as possible, provided there are no negative cross-media effects. These residues arise from different stages of the production process such as from the metallurgical operations, the smelting process as well as from the off-gas and waste water treatment.

3.10.1 Techniques for residues from the smelting process

The main residues arising from the smelting of non-ferrous metals are slag, dross and skimmings removed during the pyrometallurgical processes. Slag is generated by the reaction of slag-forming accompanying elements (e.g. Fe) with added fluxes. In the smelting process, the slag is liquid and has a different density to the melted metal and can therefore be tapped off separately.

Most of the slag generated by downstream or refining operations in non-ferrous metals production processes can usually be recycled or used for further metal recovery. There is a distinction between slag with a high metal content, which is recycled within the process or transferred to another process or site for recovery and final slag with a low metal content.

Several facilities in the non-ferrous metals industries have demonstrated that there is a market in which they are able to sell slag for further beneficial use. The use of slag as a construction material to replace aggregates is only possible if the amount of the leachable metal compounds is low.

3.10.2 Techniques for residues from abatement systems

Abatement systems are another major source of solid materials. These are flue-gas dust and sludge recovered from the air pollution control equipment (Figure 17), as well as other solid waste like spent filter material such as filter bags.

Dust from the storage and handling of raw material or from pre-processing unit operations is collected by the de-dusting system (usually a fabric filter) and sent back to the main process or another smelter. In some cases, the dust should be agglomerated before it can be recycled to the raw material storage and handling station.

Dust-laden off-gas from the smelting and refining facilities can be cleaned using different abatement techniques. The material collected as dust by the off-gas cleaning can be agglomerated and sent back to the smelter or supplied as a raw material for further metal recovery in other facilities.

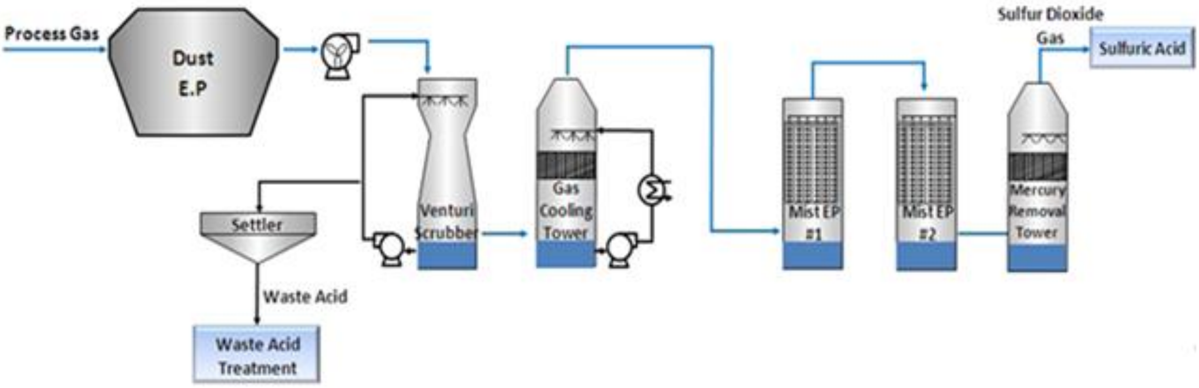

Figure 17: Representation of how flue gas is cleaned.

3.10.3 Techniques for residues from liquid effluent treatment

Pyrometallurgical processes for the production of non-ferrous metals do not normally produce harmful waste water. The water is used for the direct or indirect cooling of furnaces, blowing lances and casting machines, e.g. for copper anode or continuous casting. This water is warmed up by cooling the equipment but is normally not polluted with chemical impurities or metal particles. Therefore, cooling water is usually discharged directly back into the receiving source after settlement or another treatment step.

3.10.4 Techniques for residues from non-ferrous metals hydrometallurgical processes

The production of non-ferrous metals by hydrometallurgical processes is another significant source of solid residues. The leaching process can generate relatively large quantities of sludge (e.g. approximately 0.3 to 0.5 tonnes iron-based solids per tonne of zinc depending on the quality of the concentrate). These residues are normally disposed of in specially sealed lagoons or underground deposits, e.g. blasted mountain caverns. Some residues are also compacted or treated in the Jarofix process before disposal.

3.10.5 Techniques for other residues from the production of non-ferrous metals

Wherever practicable, waste streams incidental to the main processes should be segregated for recovery or appropriate safe disposal.

All machinery that is operated in an industrial installation uses oil as a lubricant. This should be changed, due to metal pick-up and chemical reactions in the oil. Regular maintenance, repairs and preventive maintenance can minimise oil loss by leakage and increases the intervals between the oil changes. A reduction in the quantity of used oil is also achieved using filtration, which gives an extension of the service life.

3.11 Copper energy usage

The diagram below (Figure 18) shows the energy usage in each stage of the copper production process in common units (kJ/lb Cu).

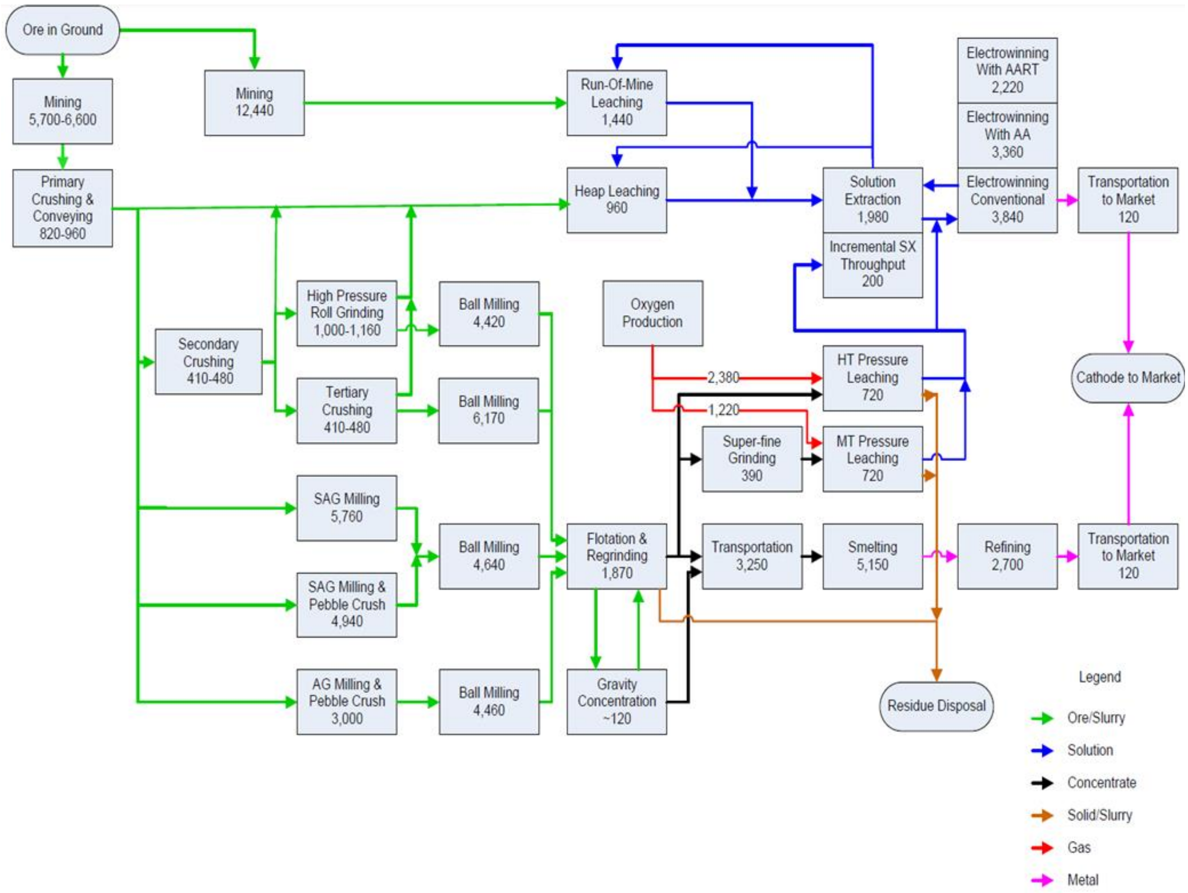

Figure 18: Energy consumption required in each stage of the copper production process.

Table 2 shows the energy consumption in the cathode copper production for the RTB Bor mine in Serbia in 2011.

Table 2: example of energy consumption in cathode copper production.

Operation	**Energy Consumption** $[t_{ec}/t_{cc}]$
Mining	1.401
Flotation process	3.280
Pyrometallurgy	2.024

Production of sulphuric acid	0.147
Electrolytic refining of copper	0.171
TOTAL:	7.023

t_{ec} = tonnes of equivalent coal, t_{cc} = tonnes of copper cathode.

This data is shown in a chart as Figure 19 (below):

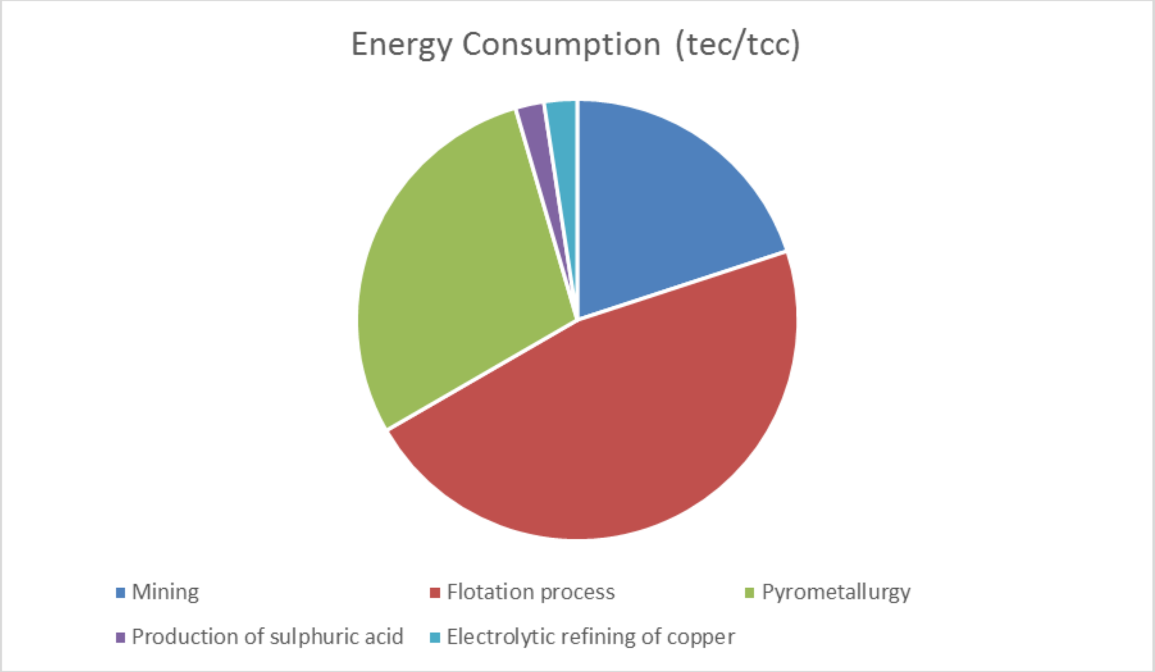

Figure 19: energy consumption at each stage of the pyrometallurgical copper production process for the BTR Bor mine in Serbia in 2011.

The production energy (net) requirement for a number of processes using copper concentrate is in the range of 14 – 20 GJ/t of copper cathode. The exact figure depends mainly on the concentrate (percentage of sulphur and iron), but the smelting unit used, the degree of oxygen enrichment and the collection and use of process heat also have an influence. Comparative data based solely on the type of smelter are therefore liable to inaccuracies. The utilisation of the energy content of the concentrate is more important and smelters that achieve autogenic operation have lower energy use.

Increasing the energy efficiency and reduction of external fuel consumption are also achieved by applying techniques to recover waste heat. The hot off-gas produced by the smelting furnace or converting vessel is sent to a heat recovery boiler. In the boiler, gas is cooled by generating steam. The steam could be used inside, for example for drying concentrate (in direct steam coil drying, 150–180 kg steam per tonne of concentrate) or for other process units, or outside for electricity production or district heat. Production of sulphuric acid from SO_2-containing off-gas also produces extra energy that could be recovered using a heat exchanger.

The energy consumed by the electrorefining stage of copper production is reported to be 300–400 kWh per tonne of copper, but the energy used is considerably higher when high impurity anodes are electrorefined. The type of blank cathode used (stainless steel or copper) mainly influences the efficiency of the tank house and this can range from 92% to 97% in terms of current efficiency.

4 Aluminium

4.1 Overview

Aluminium is a widely used material, notably in the transportation, construction and packaging industries. It is light, has good electrical conductivity and forms a surface oxide layer when exposed to air that prevents further corrosion.

4.1.1 Sources of materials

Primary aluminium is produced from bauxite that is converted into alumina; 100 tonnes of bauxite produces 40 to 50 tonnes of alumina (aluminium oxide), which can then produce 20 to 25 tonnes of aluminium. Most of the bauxite is mined outside Europe, but there are several alumina production facilities within Europe.

The secondary industry depends on the sources of scrap. Scrap can be termed 'new scrap' which is generated during the production and fabrication of wrought and cast products or 'old scrap' which is recovered from articles at the end of their useful life. The recycling rate of 'new scrap' is 100% of the amount produced.

4.1.2 Production and use

The European aluminium industry includes mining and alumina production, primary and secondary smelting and metal processing into semi-finished products (e.g. bars, profiles, wires, sheets, foils, tubes, pipes) and speciality products (e.g. powders, special alloys).

In 2007, the EU-27 accounted for about 8% of the total world production of primary aluminium.

Primary aluminium production in the EU27 is shown below (Figure 20).

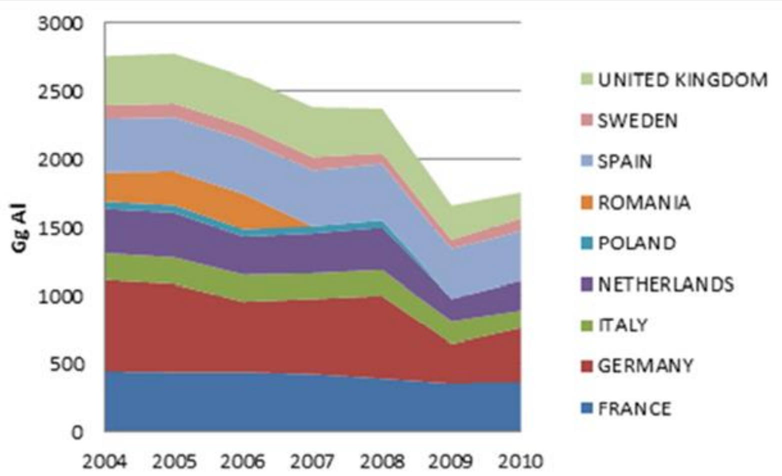

Figure 20: Primary aluminium production in the EU27.

The simplified life cycle of an aluminium product is shown below (Figure 21). Each sub-section will then be explored in more detail.

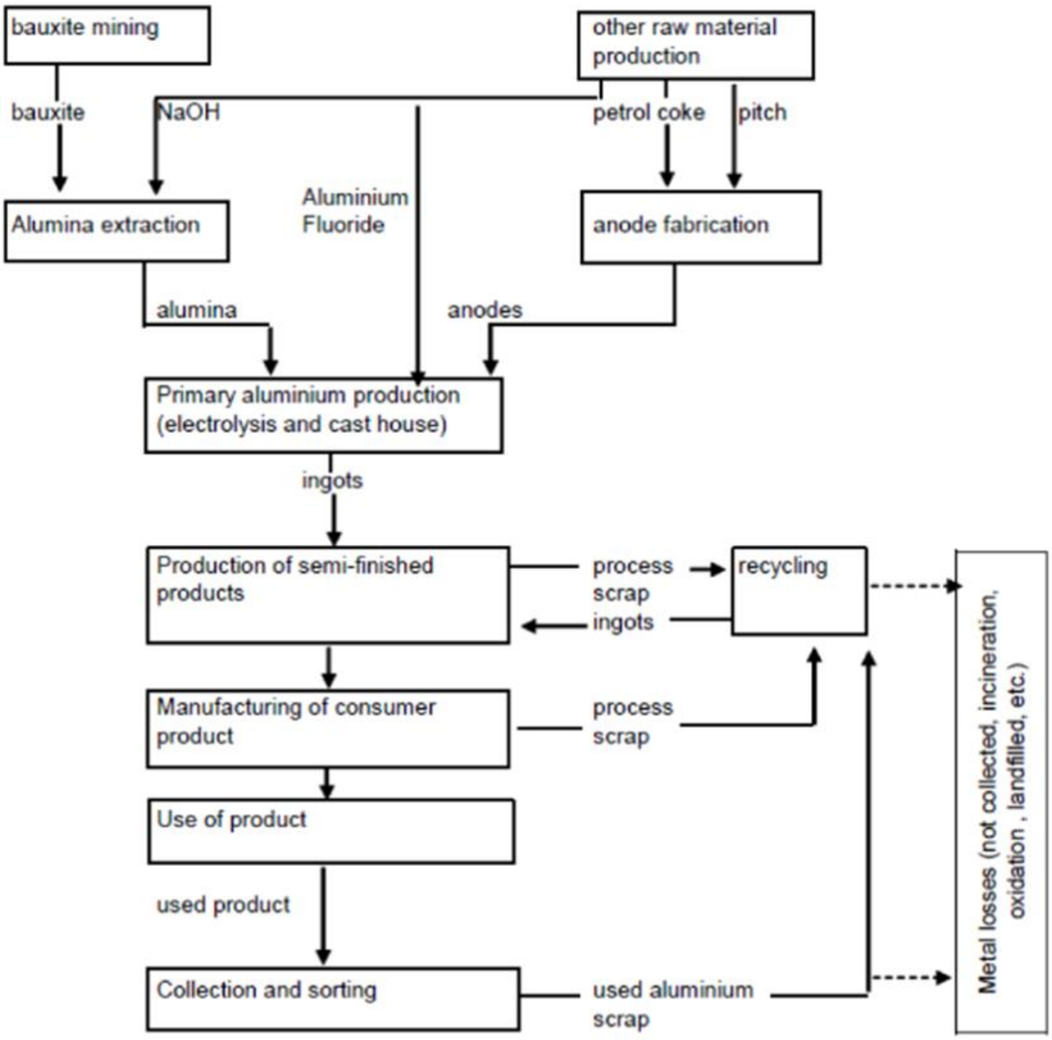

Figure 21: Simplified life-cycle flow chart of an aluminium product.

4.1.3 Raw material preparation

Raw material preparation information can be found in par.2.1.

4.1.4 Production of alumina

Alumina is usually produced from bauxite in the well-established Bayer process as represented below (Figure 22). This process utilises the different thermodynamic properties of the caustic soda - aluminium hydroxide system.

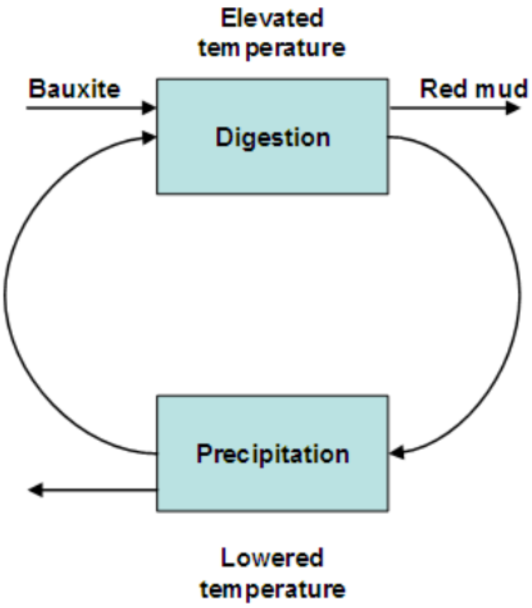

Figure 22: General principle of the Bayer process.

4.1.5 Digestion

First of all the bauxite is ground in order to make it pumpable and to increase the surface for extraction. The bauxite is ground in ball or rod mills or a combination of both and caustic soda (liquor) is added. The resultant slurry is then usually stored in slurry tanks (Figure 23). The digesters are fed with this bauxite slurry and additional liquor in order to achieve optimum dissolution properties.

The bauxite slurry is heated up to digestion temperature, which varies from 100 °C to 320 °C depending on the bauxite quality, at which temperature the aluminium compound dissolves. The hot slurry is cooled down in flash tanks. The evaporated steam is used to preheat the bauxite slurry and, thus, heat is recovered.

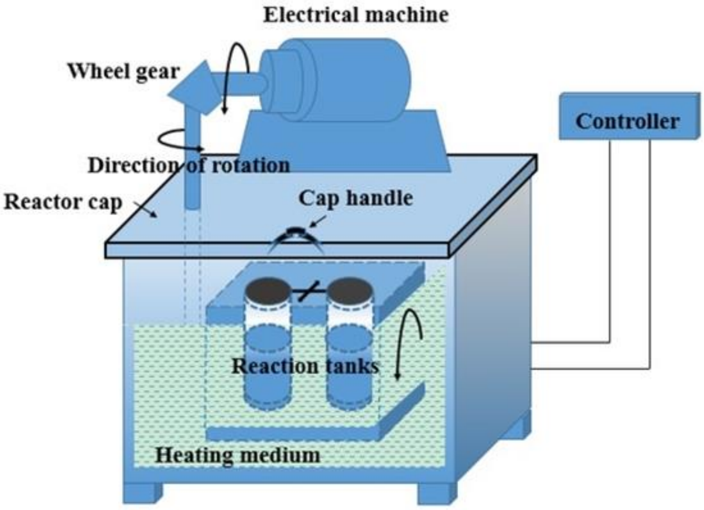

Figure 23: A representation of a bauxite digestion tank.

4.1.6 Red mud of bauxite residue removal

Bauxite residue, usually known as red mud, is the remaining solid material after the extraction of the bauxite and it does not dissolve in the liquor. It is removed from the process liquors by means of thickeners.

4.1.7 Precipitation and calcination

At first, the overflow of the settlers is filtered in order to remove the finest solid particles from the liquor. The liquor is then cooled down to the precipitation temperature and the precipitation is started by adding aluminium hydroxide as the seed.

4.1.8 Anodes for aluminium production

Carbon anodes produced for primary aluminium smelting are commonly produced on the same site as the smelter itself. In some cases though, they can be produced in stand-alone anode production plants.

Processes use coke, pitch and cleaned anode butts to produce pastes, which are then formed into anode blocks. Raw material storage and handling stages use enclosed coke delivery and handling systems and integral dust filters. A diagram representing the production of green anodes is shown below (Figure 24).

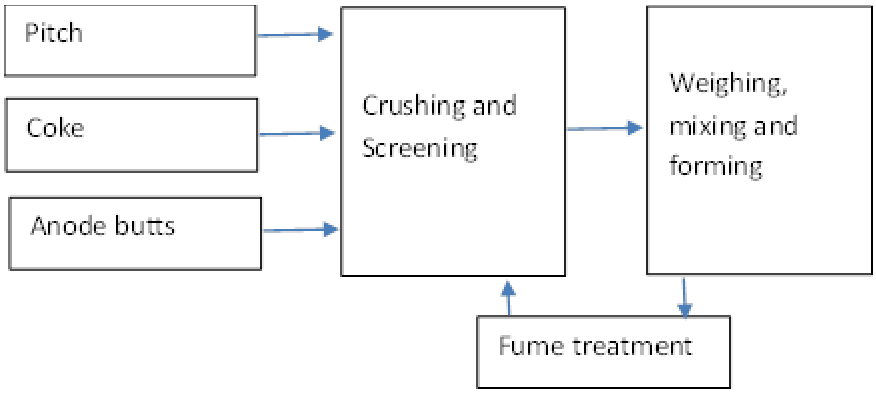

Figure 24: A diagram showing the production of green anodes.

4.2 Primary aluminium

Aluminium is produced by the electrolytic reduction of aluminium oxide (alumina) dissolved in a molten bath of mainly sodium aluminium fluoride (cryolite) at a temperature of approximately 960 °C. The electrolytic cells comprise a carbon cathode, insulated by refractory bricks inside a rectangular steel shell and carbon anodes suspended from an electrically conductive anode beam. The cells are connected in series to form an electrical reduction line (potline). A direct current is passed from the carbon anodes through the bath and a layer of metal to the cathode and then, by a set of current conductors known as 'busbars', to the next cell.

Liquid aluminium is deposited on the cathode at the bottom of the cell. Molten aluminium is periodically withdrawn from the cells by vacuum siphons into crucibles. There are two main types of electrolytic cells, Søderberg and Prebake.

4.2.1 Søderberg cells

Søderberg technology uses a continuous anode which is made *in situ* from a paste of calcined petroleum coke and coal tar pitch and is baked by the heat arising from the molten bath and the electric current through the anode. The current is fed into the Søderberg anode through studs that have to be withdrawn and re-sited higher in the anode as the anode is consumed. Diagrams of the main Søderberg cells are shown in Figure 25.

4.2.2 Prebaked cells

Prebake technology uses multiple anodes, which are manufactured from a mixture of calcined petroleum coke, clean and recycled anode butts and coal tar pitch. Anodes are formed into blocks and baked in a separate anode plant. The anode production plant is often integrated into the primary aluminium plant.

The anodes are suspended in the cells by hanger rods attached to anode beams, which also serve as the electrical conductor. The anodes are gradually lowered as they are consumed and are replaced before the rods are attacked by the molten bath.

Diagrams of the main electrolytic cells are shown below (Figure 25).

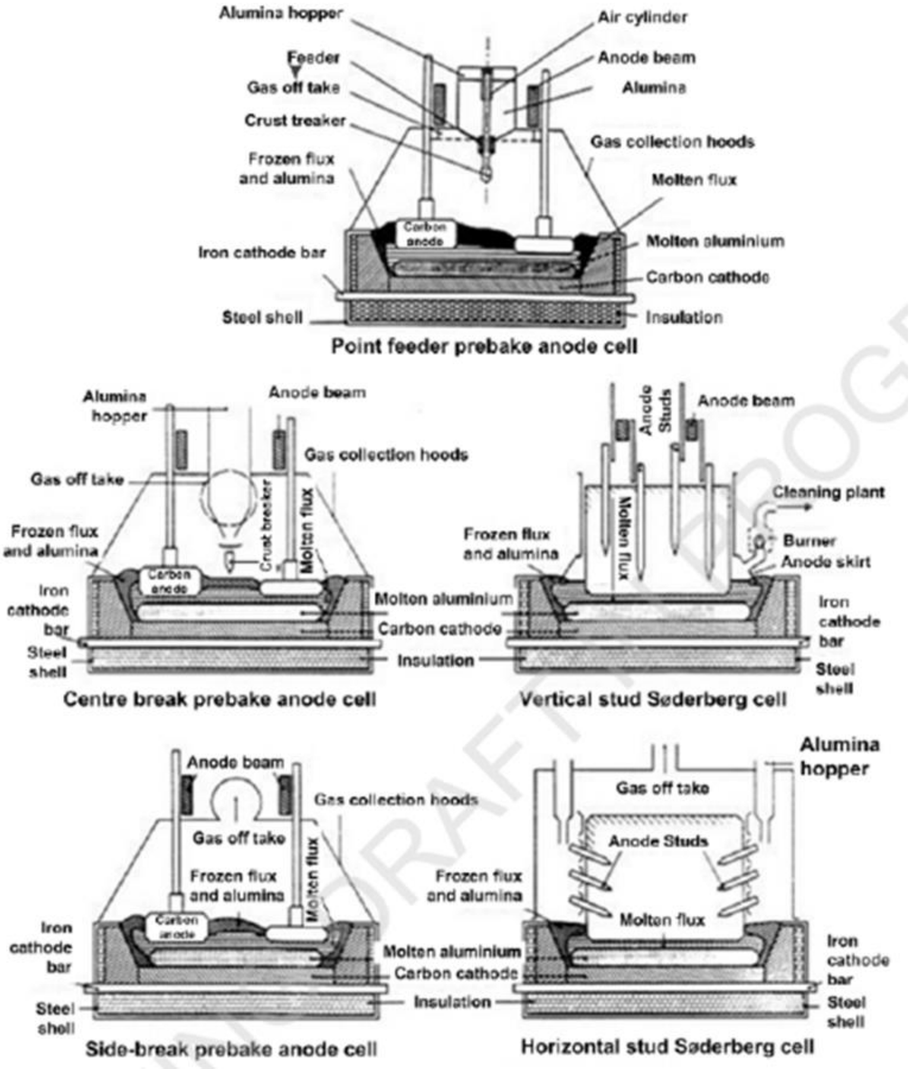

Figure 25: Diagrams of the main types of prebaked and Søderberg cells.

4.2.3 Purification

The metal is treated to remove metallic impurities such as sodium, magnesium and calcium, non-metallic particles and hydrogen. This treatment is performed in two stages: in the first stage, fluxing salts consisting of aluminium fluoride, magnesium chloride or potassium chloride are added in the furnace to remove metallic impurities and, in the second stage gas is injected into the molten metal usually in an in-line reactor.

4.2.4 Scrap melting

Primary aluminium sites melt commercial metal and scrap. The scrap melted in these sites includes internal company scrap from extrusion and rolling without substances such as paint or plastic (including customer returns without paint or plastic and scrap from sites belonging to the same company) and scrap bought on the market that does not contain substances such as paint, plastic or oil. This scrap can be melted in two ways: either in the furnace before adding liquid metal from electrolysis or by adding it to a furnace that already contains liquid metal.

4.2.5 Casting

Slabs, T-bars or billets are cast in vertical direct chill casting machines that use water-cooled metal moulds and a holding table at the bottom of the moulds. The table is lowered as the ingot is formed. Billets and slabs with smaller cross-sections can also be produced by horizontal direct chill casting.

4.3 Production of secondary aluminium

Secondary aluminium is produced from the scrap melting. Two main features of secondary aluminium production are the diversity of raw materials encountered and correspondingly the variety of furnaces used.

4.3.1 Pre-treatment

Typical sources of aluminium scrap are process scrap, used beverage cans (UBCs), foils, extrusions, commercial scraps, turnings and old rolled or cast metal. In addition, aluminium is also recovered from skimmings/dross and salt slags. Various contaminants may be present and this is taken into account in the choice of pre-treatment or in the design of the furnace.

4.3.2 Melting process

Rotary or reverberatory furnaces (Figure 26) (also known as closed well, chamber or hearth furnaces) are used for melting a wide range of secondary raw materials. Rotary furnaces can incorporate a tilting mechanism. The tilting mechanism in some cases allows increases in efficiency for melting raw materials that contain low amounts of aluminium including skimmings/dross and the amount of flux needed for these materials can also be reduced. Induction furnaces and shaft furnaces (the Meltower) are used to melt cleaner aluminium grades. Reverberatory furnaces often include a side well.

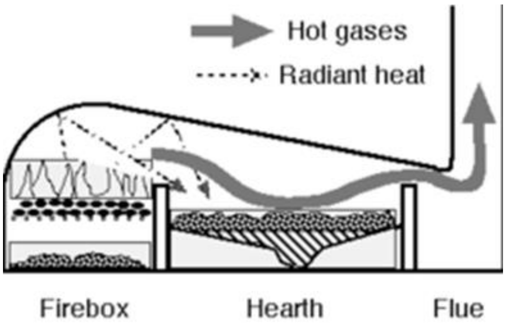

Figure 26: A diagram of a reverberatory furnace.

4.3.3 Molten metal treatment

Metal may be tapped from the melting furnace, where alloy additions are made either directly to a casting system or via a transfer system into a holding furnace (where other alloying additions can be made). The metal is then refined either in the holding furnace or in an in-line reactor, to remove gases and other metals.

4.3.4 Casting

Large ingots, billets and slabs are cast in the same way as described for primary aluminium casting.

4.4 Salt slag recovery

In secondary aluminium production, rotary or tilting rotary furnaces are used to melt various grades of scraps and also skimmings and dross. Salt flux is usually used to facilitate this process, as it reduces oxidation and promotes the removal of some impurities (e.g. Mg, Ca, Li). The used salt flux tapped from the furnace is called salt slag.

4.5 Full recycling process

The full recycling process is a combination of different physico-chemical process steps for the recovery of aluminium salt slag.

4.6 Partial recycling process

Three partial recycling processes exist:

- One is part of a fertiliser production plant that only recovers KCl and aluminium granules, while other components (sodium chloride and oxides) are used for recultivation of potash tailings piles.
- In another partial recycling process, besides the recovery of salt, all process steps are similar to full recycling. The process water and waste water from the gas cleaning treatment filter is directed to an old mine system that ends in an outlet to the sea.
- In the third one, the aluminium and the other metallic products are recovered through electromagnetic and mechanical processing and the residues are disposed of.

4.7 Aluminium energy usage

4.7.1 Production of primary aluminium

The table below shows the energy consumption per tonne of sawn aluminium ingot production. Data refers to the EU-27 plus Iceland and Norway as a whole.

On average, the specific consumption of electrical energy is approximately 55 GJ per metric tonne of aluminium, which makes electrolysis the most energy-intensive step of the whole aluminium cycle. About half of this energy is converted to heat in the process.

The material and energy inputs to the process are significant. Approximately two tonnes of bauxite are required to produce one tonne of alumina, which in turn produces about 0.53 tonnes of aluminium.

Table 3: energy consumption per tonne of each stage in the aluminium production process.

Process	**Relative amount of product used**	**Specific energy requirement** [GJ/t product]		**Total energy requirement** [GJ]		
		Thermal energy	**Electricity**	**Thermal energy**	**Electricity**	**Total**
Bauxite mining	4.5	0.02	0.003	0.089	0.013	0.10
Alumina refining	1.9	10	0.65	19	1.3	21
Anode production	0.56	2.8	0.4	1.6	0.22	1.8
Electrolysis	1.0	14(*)	55	14(*)	56	70
Ingot casting	1.0	1.6	0.4	1.6	0.40	2.0
Total	-	-	-	37	58	95

(*) – when anode carbon is regarded as fuel

This data is represented as a pie chart (Figure 27) below.

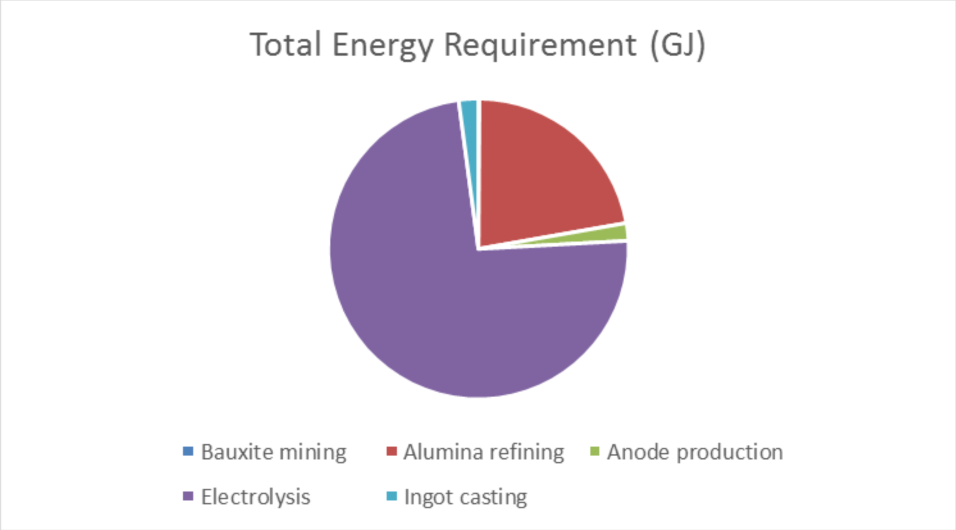

Figure 27: Energy requirement for each stage of the aluminium production process [GJ].

Table 4: Breakdown of the EU's final energy consumption for the aluminium industry.

Product	**Output** [kt]	**% of total output**	**Electrical Energy** [GWh]	**Thermal Energy** [GWh]	**Total Energy** [GWh]	**% of total energy**
Alumina	4,748	26%	-	13,734	13,734	13%
Primary	4,091	22%	61,590	16,759	78,349	76%
Rolling	3,514	19%	1,850	2,090	3,940	4%
Extrusion	2,394	13%	1,904	1,946	3,850	4%
Recycling	3,520	19%	-	3,412	3,412	3%
Total	18,267	100%	65,344	37,941	103,285	

4.7.2 Production of secondary aluminium

Secondary aluminium production requires as little as 5% of the energy needed for primary aluminium production. The production route is also much more diverse and fragmented compared to primary aluminium production.

Re-melters use mainly reverberatory furnaces while recyclers/refiners mostly use a combination of rotary and reverberatory furnaces. In short, the specific thermal and electricity input is about 3.8 GJ/t and 0.45 GJ/t, respectively. This is only a small fraction of the consumption of 37 GJ of thermal energy and 58 GJ of electricity per tonne of primary aluminium. However, this is only for secondary aluminium production from new scrap. Recycling old scrap will use somewhat more energy because of the required additional scrap preparation step.

The average specific CO_2 emission from the specific fuel consumption is around 0.265 tCO_2/t Al.