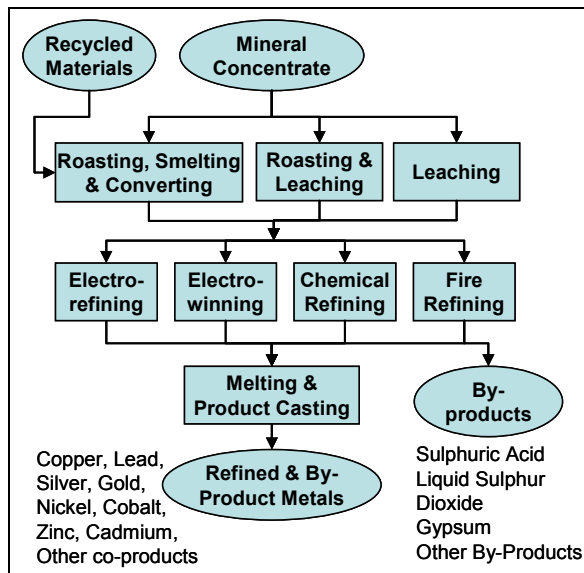


PROCESS DESCRIPTION

This guideline covers the production of non-ferrous metals from mineral concentrate. (The production of this concentrate is covered in the Mineral Processing guidelines). The processes used for smelting and refining of the majority of metals are similar and illustrated in the diagram below. Aluminium refining is covered separately. Not all processes will be used for each metal.



The production of concentrated mineral is covered in the Guideline on Mineral Processing.

- **Roasting** – this is the removal of sulphur from metal sulphide concentrates by adding air and heating/drying to achieve the desired sulphur content for smelting. Partial roasting prepares copper and nickel sulphides for matte¹ smelting; complete roasting produces a metal oxide, which can be reduced or leached. Sulphur dioxide (SO₂) is produced as an off-gas.

¹ Molten solution of metal sulphides

- **Smelting** – separates metals of value from other less desirable metals and impurities. A fluxing agent is used to remove the impurities as a slag. Off-gases include SO₂, particulates and volatile metals.
- **Converting** – air is blown through copper and nickel matte and high grade scrap to remove residual sulphur and iron. Off-gases contain SO₂ and volatile metals, e.g. lead and zinc. The slag is typically high in copper/nickel and may be returned to the smelter.
- **Leaching** – use of an acid or other solvent to dissolve the metal content from an oxidic ore or an oxide produced by roasting before refining and electro-winning. Sulphidic ores require oxidation before they can be leached. The resulting solution, is termed “pregnant” and is processed using a solvent and purified.
- **Electrowinning** – used mainly for refining zinc, copper, nickel and cobalt from the pregnant leaching solution. Electric current is passed through the solution in electrolytic cells and the dissolved metal ions are deposited on the cathode. Off-gas (or anode gas) includes oxygen and acid mist. Spent electrolyte is returned to the leaching process.
- **Electrorefining** – refines lead, nickel and copper. The metal is cast as an anode and placed in an electrolytic cell to dissolve the metal to an acidic aqueous electrolyte or molten salt. The pure metal is electroplated or deposited on the cathode, or “starter plates”. Metal impurities either dissolve or form a sludge. These may contain precious metals, which can be recovered and sold.
- **Chemical Refining** – the condensation of metal from a vapour or the selective precipitation of metal from an aqueous

solution. The impurities contain copper and precious metals, which are recovered. The carbon monoxide in the off-gas is recycled back into the process.

- **Fire or Anode Refining** – removes further impurities from metal from the converting process. Air is blown through molten mixture to oxidise the metal and volatilise sulphur, other impurities may be removed with a flux. A small amount of slag is produced. Residual oxygen is removed using natural gas, ammonia or wood. The purer copper is then cast onto anodes.
- **Casting** – The refined metal is melted and cast into billets, blocks, tubes, slabs or ingots.
- **Aluminium** – Alumina (see Mineral Processing Guideline) is electrolysed to form liquid aluminium, which collects at the bottom of the cell and is removed by vacuum tapping. Many cells may be connected in series and can produce a strong magnetic field.
- **Recycled metals** – These are pre-treated e.g. shredding, sieving, magnetic separation, drying and then smelted. Further refining as described above may be required.

KEY ENVIRONMENTAL, HEALTH AND SAFETY RISK/LIABILITY ISSUES

Air Emissions

Off-gases from the various processes contain sulphur dioxide, particulates, metal fume (volatile metals), volatile organic compounds (VOCs), acid mists, carbon dioxide and monoxide, nitrogen oxides and organics. Dioxins and furans may be formed due to the presence of small amounts of chlorine in secondary raw materials. Off-gases must be

treated to remove these pollutants before being released to air. Sulphur dioxide captured may be converted to sulphur, sulphuric acid or gypsum.

Particulates will also be released during receiving, conditioning, handling, transporting and storage of ores, concentrates and secondary raw material; during furnace processing and the movement of hot materials; during the collection and transport of abatement system contents e.g. filters; and during melting and casting. Fugitive emissions may be greater in volume than those from point sources.

The prioritised hierarchy of gas collection is:

- Process optimisation and minimisation of emissions;
- Sealed reactors and furnaces;
- Targeted fume collection.

In the majority of cases, process gases are cleaned in fabric filters reducing the emissions of dust and metal compounds such as lead. Wet scrubbers, afterburners and wet electrostatic precipitators (ESP) may also be used.

Respiratory hazard control technology, (e.g. respirators) must be used when exposure cannot be avoided, e.g. during maintenance.

For large installations, the risk of transboundary pollution must be considered.

Aluminium Process Emissions

There are some additional air emission issues which are specific to aluminium processing and these are highlighted below.

- Two perfluorocarbons (PFC) (CF₄ and C₂F₆) contribute about 48% of primary aluminium

greenhouse gas emissions and these can be up to 10,000 times more harmful than CO₂. Emissions of PFCs are strictly the result of electrolytic reduction; they are formed during the “anode effect” when the electrolyte becomes depleted in alumina and the production of aluminium is inhibited. The effect can be stopped by increasing the feed-in rate of alumina and stirring the electrolyte. A shift from older smelter technologies to newer technologies can improve energy efficiency while reducing PFC emissions, e.g. replacement of the smelter to one using Point Feeder Pre-Bake (PFPB) technology.

- Gaseous fluorides may be emitted during electrolysis. Fumes should be captured and cleaned using alumina and filters or wet scrubbers.
- Anodes are prepared onsite using carbon containing materials including petroleum pitch baked onto a metal core. Tar, polycyclic aromatic hydrocarbons (PAHs), volatile organic compounds (VOCs) and other contaminants such as sulphur can be released during the baking process. If feasible, the VOCs can be burnt within the baking furnace, the other off-gases should be treated by scrubbing or absorption followed by filtering. Hydrocarbons obtained may be returned to the production process.

Ground and groundwater contamination

Contamination of land and surface and ground waters (on or off site) can occur through sudden and accidental incidents such as major spillages or via gradual and repeated leakage of contaminants in to ground and waters. Contamination may be historical from past operations or from current activities or both.

Energy Consumption

Smelting and refining operations are energy intensive, particularly in terms of the fuel used to provide heat and generate electricity for electrolysis and to power utilities and equipment. The recovery of heat and energy is therefore important.

Wastewater

Wastewaters arising from various process stages are likely to contain soluble and insoluble metal compounds, oil and organic material. Wastewater treatment will be required. Techniques include:

- Source segregation to prevent clean water being contaminated;
- Pretreatment to reduce heavy metals;
- Oil/water separation;
- Filtration;
- Sedimentation;
- Other physical/chemical treatments;
- Dewatering of residuals prior to disposal as hazardous waste.

Where feasible, process water should be recycled back into the process.

Stormwater may become contaminated through contact with material stockpiles or airborne contaminants and where necessary should be captured and treated before discharge.

Hazardous Materials

Hazardous chemicals (acids, alkalis) and process gases are used in smelting and refining. Significant hazardous properties relating to individual chemicals include flammability, combustion potential, toxicity, corrosive potential and oxidising potential. Chemicals with such properties should be labelled with the appropriate internationally recognised diamond shaped hazard symbol². Inadequate control of hazardous chemicals can elevate the risk of major accident harming workers, the local community and the environment.

Some chemicals may only possess a hazard potential if they have the opportunity to react with other compounds. Chemicals with different hazard symbols should not be stored together - clear guidance on the compatibility of different chemicals can be obtained from the Materials Safety Data Sheet (MSDS) which should be readily available from the manufacturer and on site.

Accidental release of hazardous chemicals on site and in transit may result in explosions, air pollution and significant environmental impacts in relation to soil, groundwater and surface water contamination. Releases of hazardous substances to the air could impact the local environment including human health.

Solid Wastes

A range of hazardous and non-hazardous residues and wastes are produced including slag, spent refractory linings, waste from abatement systems, cathode waste, smelter dust, sludge from wastewater treatment and leaching, purification and electrolysis activities. This

should be weighed against the contribution made by the process in recycling metal waste.

Some by-products and wastes can be recycled back into the process, e.g. for residual metals recovery. Slag may be processed into an inert granular material that can be sold for industrial use, e.g. in cement manufacturing and insulation products.

Spent cathodes from the aluminium refining process contain soluble fluoride, cyanide, copper and zinc and produce an alkaline leachate if made wet. These should be treated and reused (e.g. in furnaces, cryolite production, cement industry, as a fuel source) or disposed of as hazardous waste.

Noise and Vibration

Sources of noise and vibration include: transport and handling of materials; furnaces; venting of steam; location and sound insulation of fans and filtration systems; casting installations; internal transport. Noise may reach levels that are hazardous to health.

OTHER ENVIRONMENTAL, HEALTH AND SAFETY RISK/LIABILITY ISSUES

Confined Spaces

Smelting and refining facilities have equipment that requires entry into dangerous confined spaces. Such entry must be strictly controlled and avoided wherever possible.

Burns and Heat Stress

High temperatures and direct infra-red radiation (IR) can cause fatigue and dehydration for those working in the vicinity. Direct IR can also cause damage to sight. Burns and scalds may occur

² United Nations 2007 (see references)

through contact with hot surfaces, metal or water especially during maintenance activities.

Polychlorinated Biphenyls (PCBs) and Asbestos

- PCBs are a group of substances which are good electrical insulators. Typically, PCBs may be present as constituents of hydraulic oils or dielectric fluids in electrical switchgear, transformers and fluorescent light starters;
- Asbestos has been used on a large scale for many years as a fire proofing and insulation material and may be encountered in a wide range of forms including asbestos cement boards, as fire retardant gaskets in pipework and as fire retardant insulation around boilers and furnaces.

Removal of these materials should be undertaken by licensed contractors where available and in all circumstances should be carried out in controlled conditions to ensure that there is not release of substances or materials to the environment

Particular attention should be given to buildings constructed before the 1980s

Permitting

Smelting and refining facilities in the EU are subject to national regulations under the Integrated Pollution Prevention and Control Directive (2008/1/EC). Operations outside the EU will still be subject to local regulations.

Machinery

Moving parts of machinery can result in entanglement and entrapment. Particular attention should be paid to conveyors.

Respiratory Disease

- Dust and spray mists created in the process can be inhaled and cause respiratory disease including asthma;
- Metal fumes may cause cancer;

Collision

This often takes the form of people being hit by moving, flying or falling objects.

Slips, Trips and Falls

These often occur on the same level and are primarily caused by uneven surfaces, inappropriate footwear, lighting, weather conditions, trailing cables and pipe work, especially during unblocking, maintenance and cleaning activities.

Manual Handling and Repetitive Work

Lifting and carrying heavy or awkwardly shaped objects, such as bags, can result in manual handling injuries.

KEY SOCIAL, LABOUR AND COMMUNITY RISK/LIABILITY ISSUES

Accumulative Contamination

The slow build-up of contaminants on land and dwellings in the community through the deposition of fine metal particulate and other pollutants can expose residents and the ecosystem to health risks. Crop and livestock production and quality may be affected. The use of on site emission controls will minimise such impacts.

OTHER SOCIAL, LABOUR AND COMMUNITY RISK/LIABILITY ISSUES

Dust and Odour

- Public/environmental health and nuisance issues associated with dust and vented fumes can arise from production activities and may have a significant effect on neighbouring locations. This may be important if there are neighbouring residential and industrial activities in the area;
- Some of the substances produced or used have the potential to cause offensive odour to neighbouring communities.

Transport

Transport of products by either road can be a significant issue. This might lead to road noise and traffic congestion.

FINANCIAL IMPLICATIONS

- Many countries are signatories to the Kyoto Protocol and have adopted targets for the reduction of CO₂ emissions. Where Governments have set up carbon emission reduction programmes industrial processes have been required to reduce their CO₂ emissions through the setting of targets. This can result in a need for substantial investment in new/clean technologies to achieve the emission targets. These targets may be reflected in environmental permits;
- Under the EU Emissions Trading Scheme (ETS) Member States allocate allowances for carbon emissions to industrial sites, including smelting and refining facilities. The scheme can create both financial assets or liabilities and entities can trade their carbon allowances;

- Injuries may lead to increased payroll costs to replace skilled workers and lost production time;
- Capital investment may be required to comply with new environmental, health and safety requirements;
- There is a relatively high potential for soil and groundwater contamination to be present which can be very costly to remediate;
- Fines, penalties and third party claims may be incurred for non-compliance with environment, health and safety regulations.

IMPROVEMENTS

Environmental, Health and Safety Improvements

General

- Environment, health and safety training for all employees and contractors
- Good housekeeping should be maintained at all times in all areas to reduce the likelihood of incidents and accidents.

Airborne Emissions

- To minimise airborne emissions:
 - Cover all transport vehicles and storage areas to reduce dust;
 - Transfer with pneumatic or enclosed conveyor systems;
 - Wet with water or suppressants to minimise airborne contaminants from roadways, storage areas etc;

- Optimise process design to reduce off-gas emissions and pollutant content; design for continuous operation where possible;
- Use sealed furnaces and reactors/retrofit existing furnaces with maximum sealing;
- Installation or upgrade of abatement technology to minimise exposure to toxic raw materials and product and to control the release of emissions, e.g. enclosure of equipment, cover electrolytic cells, appropriate ventilation with filters, gas balancing systems, baghouses;
- Implement a formal Leak Detection and Repair (LDAR) programme and where necessary, replace with higher quality items, any equipment which generate significant fugitive emissions;
- Monitor and control anode effects;
- Consider upgrade of smelter technology when feasible to reduce anode effect emissions and decrease energy consumption.

Noise

- Enclose noisy machines to isolate people from the noise where practicable;
- Reduce exposure times for people working near noisy machinery and provide personal protective equipment where people have to enter noisy areas;

Heat

- Shield surfaces where close contact is expected. Implement safety buffer zones;

- Reduce exposure times for people working in extreme heat and provide personal protective equipment to provide protection from hot surfaces and materials;
- Install cooling ventilation.

Water Management

- Minimise the consumption of water in the process and equipment cleaning;
- Segregate process water, rainwater and indirect cooling water streams to reduce the hydraulic loading to waste water treatment equipment or sewers;
- Consider upgrades to wastewater treatment facilities;
- Use dry cleaning methods wherever practicable for solids, e.g. vacuum extraction, wipe down equipment that is accessible rather than washing and rinsing it;
- Where possible recycle wastewater back to the processes or to secondary uses such as for cleaning;
- Maintain on site abatement equipment and wastewater treatment plant;

Energy Efficiency

- Improve insulation to minimise heat loss;
- Use heat and energy recovery techniques such as steam raising boilers to capture hot gases and the use of heat generated by smelting and refining processes to melt secondary material;
- Improve system power factor to reduce distribution losses.

Fuel and storage of materials in bulk

- What fuels and materials are stored in bulk on site?
- To gauge the potential for spillages and leaks consider the following:
 - Are there any underground storage tanks? If there are, the risk of contamination of ground/ground water increases, especially where older infra structure is in place.
 - Are surface storage tanks and usage areas hard surfaced and contained? Are these in good condition or are cracks present? Are these regularly tested for leakages? Are alarms installed to detect any leaks from storage areas?

Waste

- Recover and re-use raw materials and waste products where practicable. Consider opportunities for commercial sale of recovered product.

Health & Safety

- Provision of personal protective equipment (PPE) that is fit for the task to prevent injury and maintain hygiene standards. Staff should be trained in the correct selection, use and maintenance of PPE;
- Redesign manual processes to avoid heavy lifting/repetitive activities;
- Install mechanical lifting aids where possible and rotate work tasks to reduce repetitive activities;
- Separate people from vehicles and machinery where practicable;

- Ensure that the process layout reduces opportunities for process activities to cross paths;

- Install safeguards on moving parts of conveyor belts to reduce risk of entrapment of employees;

- Install walkways and signage to separate people from vehicle movements to reduce risk of collision.

- Route cables and pipework under walkways to prevent slips, trips and falls;
- Construct walkways of non-slip materials.

Fire & Explosion

- Control the effect of fires and explosions by segregating process, storage, utility and safe areas;
- Avoid potential sources of ignition including banning smoking in and around facilities;
- Use explosion-proof equipment and conductive materials and ensure that equipment is grounded and bonded;

Emergency Preparedness

- Introduce accident, fire and explosion precautions and emergency response procedures;
- Provide the local fire department with a list and volume of products stored on the premises;
- Emergency storage lagoons may be needed to prevent contaminated firewater reaching watercourses.

Social Community and Labour Improvements

- Implement a programme of assessment of routine monitoring of worker health;
- Implement a grievance/dispute resolution mechanism for workers and members of the community to raise issues with the Company.

GUIDE TO INITIAL DUE DILIGENCE SITE VISITS

During the initial site visit, the issues will vary according to the type of process being used and product being produced and depending on the level of environment, health and safety management already introduced. While visiting the site it is important to discuss and review the following:

- Confirm organisational responsibilities and systems for environment, health, safety and social matters and that these systems cover both employees employed directly and sub-contractors;
- What processes are undertaken and are any hazardous chemicals used? How hazardous are the materials and have associated risks been documented and addressed in appropriate systems?
- Note signs of poor housekeeping, inadequate/untidy storage areas and poor drum labelling;

Air Emissions Management (including noise)

- Are there any dust control measures? Do these work and are these used? Is there any build-up of dust on machinery or other surfaces?

- Is ore moved around the site by conveyor or by vehicle?
- Note the noise levels at the site. Is there any evidence of noise/dust abatement measures deployed.

Water Abstraction & Management

- What amounts and quality of water are required? Where is the water obtained from? Is the water recycled? Will there be any planned changes which may affect the demand for water. Will existing resources be able to meet demand?

Waste water Management

- What liquid effluents are produced? What discharge control measures are employed?
- Is effluent and wastewater treated before discharge? If so, check the condition of the treatment plant and location of discharge points for effluent and wastewater from the facility;
- What does the quality of these discharges look like? Note the colour and appearance of adjacent watercourses;
- Note whether the wastewater treatment plant discharges to ground, a local watercourse or the municipal wastewater treatment works. Higher environmental risks will be associated with facilities discharging to water courses without adequate treatment;
- Is the quality tested? What are the waters tested for? Where are the samples taken from, how often? Do the discharges have to meet set standards?

- Efficiency of wastewater treatment (facility/municipal) is critical - check type, effectiveness, monitoring, final effluent and sludge disposal. Regulatory compliance discharge consents, enforcement, costs;
- Are there any other discharges of effluent off the site?
- Will any of the proposals lead to change in the type/volume of waste-water produced? Will the existing waste water infra – structure be able to treat expected volumes?
- Where are the areas for loading/unloading of material located? Are they located near any water bodies or other possibly sensitive features? Is there any containment to prevent run-off of contaminated water?
- Does road haulage cause excessive traffic through any neighbouring residential areas?

Solid Waste Management

- Note nature of solid waste disposal;
- Check that solid waste storage equipment is in a good condition;
- Check that waste storage areas are clear of debris and that skips are covered to prevent waste escaping, for example, check that waste containers have lids or are stored in an area with a roof;
- Check for flora/vegetation zones near storage sites that are not growing very well as this will indicate the possibility of pollution.
- Check that the hazardous waste, such as, cathode waste and smelter dust is removed using the appropriate contractors and check that the waste is being taken to an appropriate waste disposal facility.

Transport of Prepared Mineral off the Site

- Is this by rail, road or water or a combination of these? Will any planned changes lead to increases or decreases in the type and number of transport movements? What are the potential impacts of this?

Storage

- Check the condition of storage facilities for raw materials, finished products and fuel?
- Are there any underground fuel storage tanks?
- Evaluate potential for spillages and leakages to enter soil or stormwater drainage system. Are surface tanks and usage areas hard surfaced and bunded? Are these in good condition? Is the volume of the bunded area adequate to contain the stored materials? Are they regularly cleaned and inspected?

Health & Safety

- Are staff wearing Personal Protective Equipment?
- Check signage around the site:
 - Does it convey the health and safety risks?
 - Are fire exits and/or evacuation routes clearly marked?
 - Are there demarcated routes for pedestrians and vehicles?
- Is fire fighting and first aid equipment available? Is there a trained and competent fire fighting resource on site?

- Check the age and condition of equipment, look for signs of wear and tear, degradation, leaks and breaks;
- Check for automatic safeguards on machinery to prevent accidental injury;
- Is there worker health monitoring programme? What does it check for?

Incident Management

- Is fire fighting and first aid equipment available? Is there a trained and competent fire fighting resource on site?
- Have there been any recent incidents on site such as fatalities, fires/explosions, spills?
- Assess emergency responses to fires, major spills and major spills (in some countries it may be a legal requirement to have an emergency response plan). Does the organisation have an emergency response plan?
- Does the organisation have insurance to cover any significant damage to the environment/community/operations (this may be covered by public liability insurance or the organisation may be party to an industry insurance scheme). Review the terms of the cover.

Inspections & Regulation

- Check the conditions and duration of validity for all permits. Will any planned changes at the facility require revisions to the permits or require new consents?;
- What systems are in place to check and maintain assets and infrastructure?

- Have the premises been inspected recently by the regulatory authorities for health and safety, labour conditions, hygiene and environment? What were their findings?
- Has the organisation been subject to environment, health and safety or quality audits by customers/insurers? What was the outcome of these audits?
- Does the organisation have insurance in place to cover the recall of products? Have there been any recent product recall incidents? If yes, what did these relate to?
- Does the organisation have insurance to cover any significant damage to the environment/community/operations? Review the terms of the cover and identify any exclusions relevant to environmental and health and safety matters.
- Review historical and projected trends for environmental fees and fines. It is also suggested that contact is made with local regulatory agencies to determine compliance and whether complaints have been made by the public.

Investment

- Review budgets for capital expenditure (capex) and operational expenditure to cover EHS matters. Does the business plan have line items for Environment, Health and Safety improvements as well as asset management and maintenance?
- If investment or refinancing will lead to restructuring of the organisation what will be the potential impacts on health and safety at the operation and wider community? Have these been considered and assessed by the company?

- If the company plans to invest in new technology, what will be the impacts and benefits for human resources?

Social, Labour and Community

- Check that labour standards, contracting and remuneration are in line with national law and are consistent with the average for the sector;
- Check that hours worked, including overtime, are recorded and staff should receive written details of hours worked and payment received;
- Check that wages and working hours are consistent with the average for the sector and national standards;
- Has the Company received inspections from the local labour inspectorate in the previous three years? Have these resulted in any penalties, fines, major recommendations or corrective action plans?
- Does the organisation have a grievance mechanism, which allows employees to raise workplace concerns?
- Are employees free to form, or join, a worker's organisation of their choosing?

Take note/ask questions relating to any activities that address the improvements listed in the improvements section of this document

ACTION PLANS

Dependent on the individual business, select appropriate improvements from the list above to include in the action plan. As a minimum, any business should be required to have the following in place:

Environmental, Health and Safety

- Operational procedures to manage environmental, health, safety and social risks;
- Monitoring programmes;
- Improvement objectives, targets and project plans, for example:
 - Training for personnel, including ensuring that personnel are trained in the risk associated with their job and the correct use of personal protective equipment;
 - Regular inspections, checks and audits with records to demonstrate achievement of the required level of performance against legal requirements and improvement action;
- Operational procedures to manage environmental, health, safety and social risks;
- Energy conservation schemes and development of programmes to reduce greenhouse gas emissions;
- Emergency plans for environment, health and safety accidents;
- Management review/demonstrated involvement in environment, health, safety and hygiene management;
- Waste management plan (waste minimisation, re-use, recycling, monitoring);
- Closure and Remediation Plan;
- Stakeholder Engagement Plan;
- Senior management review/demonstrated involvement in environment, health, safety and hygiene management. Financial



European Bank
for Reconstruction and Development

Sub-sectoral Environmental and Social Guidelines: Metal Smelting and Refining

investment plans directly or indirectly related
to management of Environment, Health &
Safety and Social issues.



European Bank
for Reconstruction and Development

Sub-sectoral Environmental and Social Guidelines: Metal Smelting and Refining

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