Refinables Project
Process definitions hydro-, electro- and pyro-metallurgical processes and reclaiming

Hydrometallurgical Processes are metallurgical processes that occur in an aqueous, water-containing or water-like medium, and are mainly mediated by substances' reactivity in this medium, i.e. their solubility, speciation, ligand coordination, acid/base and redox behaviour. Typical hydrometallurgical processes include dissolution, leaching, precipitation, crystallization, ion exchange, adsorption, extraction, distillation, reduction/cementation, and also electrochemical processes.

The following PM Refinables/Intermediates[1] originate from the following processes:

- **Leaching and Dissolution:** *Leaching* refers to the intended dissolution and removal of at least one part or component from a material, leaving at least one other part of the material undissolved (this also includes "*washing*" with neutral, acidic or basic solutions; as well as reactive *distillation*). Leaching can also be performed in conjunction with a chemical transformation or modification of at least one part of the material (e.g. to suppress its dissolution; Example: Adding a reduction agent to a suspension of precious metal oxide, to transform it into the metal state, while leaching soluble salts from a mixture containing it). *Dissolution* would refer to a process intended to dissolve the whole material. However, there is not always a guarantee that a dissolution process will be able to actually dissolve the whole material, or during the process new insoluble components are formed, which then precipitate. Since both Leaching and Dissolution leave a solid residue as a Refinable or Intermediate, these processes cannot be distinguished strictly from each other. Therefore, solid residues left after such a process shall be grouped as **Residues from Leaching and Dissolution**.
- **Precipitation and Crystallization:** Precipitation and crystallization refer to the formation of an insoluble compound from a dissolved species by addition of a precipitation agent or changing the medium's characteristics (concentration, temperature, pH, polarity). The insoluble compound forms a solid precipitate that is collected as a Refinable or Intermediate **"Precipitates from Precious Metal Refining"**.
- **Cementation, Reduction, Electrowinning:** Cementation and Reduction refer to the targeted creation of a metal in its elemental/metallic state from a dissolved species by the addition of a reduction agent (e.g. a more electropositive metal = *cementation*; reduction agents like hydrazine, formaldehyde etc. = *reduction*; enforced by an electric current = electrodeposition, electrowinning). Since metals are not (physically) soluble in aqueous media, they form a metallic precipitate that is collected as a Refinable or Intermediate **"Residues, precious metal refining and reduction"**.
- **Adsorption:** PMs can be removed from solutions by contacting the solution with a solid phase. The PM is depleted from the solution and collected on the solid phase by physisorption (= adsorption), electrostatic attraction (= ion exchange) or the formation of a chemical bond (= chemisorption; scavenging). When the solid phase has reached its end of life, it is sent to Refining to reclaim the PM content. Since this is an end-of-life product, and not different from e.g. a spent heterogeneous catalyst, it is grouped with **Materials for Reclaim, PM with or without support** (see below).
- **Solvent Extraction:** Extraction refers to the intense contacting of two immiscible liquids. Some dissolved species are transported from one liquid to the other (by higher solubility in the other liquid, ion exchange phenomena, chemical bond formation, etc.): they are extracted. The liquid phases are separated from each other. The liquid phase carrying the extracted species can be contacted with a third immiscible liquid to remove an extracted species again ("stripping", back-extraction). Throughout the consortium, solvent extraction is performed in a way that no process-specific intermediates/Refinables are isolated and would need to be registered.
- **Electrochemical refining (also sometimes "electrolysis"):** *Electrochemical Processes* are mediated by a passage of direct electric current from an external source through a medium, resulting in a chemical (redox) reaction at the electrodes. In the PM industry, this is mostly referring to *Electrochemical refining*: The simultaneous electrochemical dissolution of crude

Commented [RC1]: The Leaching Residues and Precipitates are currently grouped together as „Sludges". Depending on the outcome of the "structural identity exercise", they can stay grouped or will need to be split.

[1] This document only covers the solid Refinables generated. The liquid intermediates / solutions are mostly non-isolated intermediates subject to further processing, but they are isolated in some plants. They may be considered mixtures. In the SID Guidance, the definition of a mixture includes the reference to solution ('Mixture or solution composed of two or more substances.'). These liquid intermediates could thus be considered as a mixture of UVCBs. It is up to PMC Members to make the correct interpretation and inform the PMC Secretariat if additional Refinables need to be registered.

metal at one electrode and electrochemical deposition of higher purity metal on the other electrode, while the impurities are collected as a solid forming and precipitating in the medium ("anode slime"), or remain in the electrolyte. Both are periodically or continuously removed from the system as the Refinables or Intermediates **"Slimes from Electrorefining"** and **"Spent electrolyte"**.

Commented [RC2]: The differentiation between Ag and Au electrolytes/slimes will then be based on „splitting by source", if necessary at all.

Pyrometallurgical Processes are metallurgical processes mediated and dominated by high temperatures. The high temperature is used to

- (Create and) remove volatile components
- Adjust the chemical or physical form of a material
- enforce a (otherwise usually slow or incomplete) chemical reaction, e.g. between a solid and a gas,
- or to melt materials that are otherwise solid at ambient temperature, and make use of their properties and reactivity in their molten state.

Typical examples of pyrometallurgical processes include roasting, sintering, calcining, chlorination, fusion, melting and smelting.

- **Sintering:** Heating a solid substance to a temperature, at which it is not or only partially melted, and particles start to adhese and build agglomerates and larger, more robust structures. Since this is not accompanied by a chemical reaction, the output material is identical to the input material and does not need to be registered as a different Refinable.

- **Thermal Treatment:** Heating a material is usually performed to enforce a certain reaction of the material that only occurs at higher temperatures. These reactions usually include decomposition of the material itself, yielding more volatile compounds (calcination, pyrolysis); or the reaction with a (reducing or oxidizing) gas (incineration, roasting, chlorination, reduction); reaction with a molten flux (fusion); and removal of volatile compounds (drying, fuming). In reality, the material actually undergoes several of these processes during a thermal treatment simultaneously.
  Example: A wet Pd on carbon catalyst heated under air will decompose to CO and CO_2, which are evaporated together with the water content, while the Pd partially reacts to PdO, and other metallic constituents will react to their oxides. Thus, processes that include the heating of a material in a gas atmosphere (inert, oxidizing or reducing) without a solvent, and/or only under partial melting of the material, will be grouped under *Thermal Treatment*. A Thermal Treatment process results in the generation of a **Refinable Material for Reclaim, PM with and without support**.

- **Smelting:** In the PM industry, Smelting is a process to separate precious metal from usually insoluble materials. To accomplish that, the material is mixed with additives/fluxes, and heated up to melting. In contrast to a Melting process, chemical reactions now take place, which usually cover the reduction of PMs and other metals in the material by a reduction agent, oxidation of less noble metals by an oxidant, alloy formation between metals, mixed sulfide formation, as well as mixed oxide formation. In contrast to a Fusion process, a smelting process results in two liquid phases which are immiscible and thus separated from each other: A **slag** (containing mixed oxides, fluxes,…) and an **Enriched Phase** (Alloys = **Doré**, **Lead bullion PGM rich, Iron bullion PGM rich, Copper bullion PGM rich**; PM-containing sulfides = **matte, precious metal**).

Commented [RC3]: Slag is further split by source: Dore, and non-Dore.

- **Melting:** Heating a solid substance to or above a temperature at which it becomes a liquid. Usually this is performed to change the physical form of a material, like granulation or ingot casting. Since this is not accompanied by a chemical reaction (in contrast to smelting and fusion processes), the output material is identical to the input material and does not need to be registered as a different Refinable.

Commented [k4]: The entrained slag that separates off during the melting process was originally produced in the smelting process and is therefore the same? Alternatively the quantities are so small (<1 t/a) they can be ignored for registration purposes.

- **Drying:** Heating (<180°C) a material to remove moisture. Since this is not accompanied by a chemical reaction, the output material is identical to the input material and does not need to be registered as a different Refinable.

There are also unspecific or multiple processes that will however lead to the production of a PM containing material, which will be sent to Refining due to its PM content. These **Materials for Reclaim** originate from the production, processing, or use of PM-containing materials and products.

Specifically:

- **Dust collection:** In many processes during production or processing, also refining, of PM-containing materials, dusts are generated and collected in appropriate facilities. These processes can include milling, thermal treatment, melting, smelting, grinding or polishing. Commonly, dusts from several processes are collected through a single exhaust gas filtering system at a site. This mixture of filter dusts is then sent to Refining to reclaim the PM as a Refinable **Flue Dusts, PM Refining**.
- **Mechanical Cleaning:** The processing and refining of PM-contg. materials can leave unintentionally created by-products like dusts, stains and residues. It is common practice in PM processing industry to clean floors and equipment regularly, to collect any residues of PM-containing material on them and reclaim the PM value. The resulting scraps, sweeps and cleaning tools (like swipes) are usually collected from several facilities and processes and combined before sent to refining as **PM production by-products**.
- **Equipment to process PM-contg. Materials:** Parts of an equipment in which PM is processed can become contaminated permanently with PM, which has to be reclaimed when it has reached its end of life. These are sent to Refining as **PMs in bricks, trays, crucibles etc.**
- **Use of PM products:** There is a variety of products based on precious metals for a plethora of applications; these include catalysts, jewelry, dental alloys, sensors, wires, sputter targets, solders, pastes, plating solutions, and many more. Due to their PM content, any end of life product as well as out-of-spec products or production wastes are sent to PM refining as **PMs with and without support** to reclaim the high value.