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

The following PGM Refinables/Intermediates 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). 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 reductant 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 Intermediate, they cannot be distinguished strictly from another. 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 and Reduction:** Cementation and Reduction refer to the 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). 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 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 so different from e.g. a spent catalyst, it is grouped with **Materials for Reclaim, PM with or without support** (see below).

Electrometallurgical Processes are metallurgical processes that are mediated by a flow of electric current from an external source through a medium, to enforce a chemical redox reaction. In most cases, the reaction is a dissolution or deposition of one or more metals. In the PM industry, this is mostly referring to:

- **Electrowinning:** The removal of dissolved or colloidal (precious) metals from solution by an electric current, mostly as metallic layer a on a substrate (like the electrode itself) or a metallic precipitate. In principle, this is the same reaction as forming a metallic precipitate by adding a reductant or a more electropositive metal to the solution, thus forming an identical

Commented [RC1]: The example given can also be seen as a reduction, then the residue would be considered a cement under this definition. Whatever is more reasonable for the Workgroup ☺

Commented [RC2]: Do we need to include distillation here?

Commented [RC3]: Do we need to include Electrodissolution? (does it leave a Refinable?)

or comparable metallic solid. If this solid cannot be deemed a pure substance and registered as such, it is therefore reasonable to group such a Refinable/Intermediate with "**Residues, precious metal refining and reduction**", in spite of the different processes they originate from.

- **Electrorefining (also sometimes "electrolysis"):** The simultaneous electrochemical dissolution of crude 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 [RC4]: A little „trick" to keep only electrorefining refinables (the electrolytes and the slimes) under Electrometallurgical processes

Commented [RC5]: The differentiation between Ag and Au electrolytes/slimes will then be based on „splitting by source".

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); 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 impurities 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*, and the resulting residues present the Refinable/Intermediate group of **Ashes**.
- **Fusion:** A fusion process uses the reactivity of a material (the "flux"), that is otherwise solid at ambient conditions, in its molten state at higher temperatures. The molten flux reacts with the PM-contg. material that is to be processes by physical (dissolution) and chemical (oxidation, reduction, acid-base reactions) phenomena. At the end of the process, the mixture is cooled, and a solid **fusion cake** is obtained. To distinguish a Fusion from a Smelting process: In a Fusion process only one liquid phase is present.
- **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,

Commented [RC6]: This is not a Refinable yet. My suggestion is to name it "Fusion Cake", but there might be better names. There is also the possibility to consider a fusion cake actually a *mixture* between the flux and a Leaching Residue, or the flux and an Ash.

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 a PM-enriched phase (**PM collector alloys**, PM-containing sulfides = **PM smelting matte**).

- **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. However, during melting some impurities will usually segregate from the material, which are usually collected by a small amount of fluxing agent forming a slag, and removed prior to or after cooling the molten material.

Commented [RC7]: Can we give a justification that Slags from Melting and Smelting can be grouped?

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:** 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 sweeps and cleaning tools (like swipes) are usually collected from several facilities and processes and combined before sent to refining as **PM scraps and sweeps**.
- **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.