A closed-loop technology for metals recovery from e-waste: FENIX Project

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Abstract: Precious metals recovery from waste (in particular, electronic waste) has gained a high interest for the worldwide researchers. This is due to their large number of applications and also to achieve a conservation of primary raw materials. In other words, to apply the principle of circular economy. Therefore, using this approach, we are currently under progress with the development of a closed-loop process where the noble base metals coming from e-waste recycling are further used in the manufacturing of new products. This makes the objective of an European Project with the acronym FENIX which will last till the end of 2020. For the recovery of base and precious metals, innovative bio and hydrometallurgical process will be used. Then, the achieved products will be used for additive manufacturing of new electronic products and jewelries.
Keywords: electronic waste; base metals; precious metals; 3D Printing/Additive Manufacturing.

1. Introduction

Scraps of electrical and electronic equipments have gained a large interest of recycling from both environmental and economic points of views. This is due to their very complex mixture of valuable noble metals, hazardous and highly toxic materials. However, their recycling potential in a proper way is currently sill low: about 25% in EU states [1] and 40% in USA [2]. In addition, it is estimated that 13-34% of the e-waste generated each year (about 41 MT [3]), in generally, is sent to developing Asian countries such as China and India [4]. In order to achieve Best Available Treatment, Recovery and Recycling Techniques (BATRRT) for WEEE control and diversification from landfill, the EU Commission has implemented the WEEE Directive [5] and RoHS Directive [6]. In this way, a high attention has been given firstly to restriction of six dangerous substances uses in the manufacturing of new products (WEEE Directive) and then to activities of prioritizing reuse and remanufacturing and of support for the "circular economy" (RoHS Directive). Moreover, in order to encourage the producers to design electrical and electronic goods that can be repaired, reused and recycled, the Extended Producer Responsibility (EPR) was also introduced by EU Commission within the WEEE Directive.

As in the composition of these wastes, the concentration of valuable elements (Au, Ag, Pt, Pd, Ta, Nd, Pr) is much higher than their primary ore, these are considered an important secondary resource. As was shown in the United Nation University press article [7], over of 290.3 t/year of Au and 6803.89 t/year of Ag have been used in the manufacturing of electronic products. Therefore, these devices at their end of life can offer an important secondary resource of these precious metals. They are mostly used in the manufacturing of printed circuit boards (Au, Ag, Pt, Pd), permanent magnets (Nd, Pr), and more small electronic components (capacitors, IC chips, etc.). The printed circuit boards, which represent a main component of most of all electronic and electrical products, have a different average weight and also content of precious metals. As was shown in the study published by Wang et al [8], the content of PCB in mobile phones, computers, televisions, washing machines, air conditioners and refrigerators is of 25, 20, 9, 4, 2 and 1 %. However, these precious metals do not present the same content in all the devices. Between all these, the printed circuit boards of mobile phones and computers present the highest content of these precious metals. Therefore, as is shown in literature data, most of the experimental work have been generally focused in the treatment of these two equipments printed circuit boards. In order to achieve the recovery and reuse of the noble elements content from these wastes, there have been proposed various pyro, hydro, bio-hydrometallurgical and physical-mechanical procedures. Most of the papers suggest that the hydrometallurgical procedures are the most convenient as they are more fast, more easily to control and also due to their efficiency of recovery and high grade purity of the final products.

Considering these facts, the idea of involving hydrometallurgical procedures for recovery of Au, Ag, Sn, Cu, Al, Ni and also plastic materials from waste printed circuit boards and their further reuse in the manufacturing of new products by 3D Printing (Additive Manufacturing/Rapid Prototyping) technology has been implemented within the framework of a European Project from the program Horizon 2020 named FENIX (Future business models for the Efficient recovery of Natural and Industrial secondary resources in eXtended supply chains contexts). In this way, the circular economy principle is wanted to be achieved even by application of the developed procedures in demonstrative small pilot plants. Furthermore, the main data regarding the circular economy, 3D printing and FENIX project are present.

2. Circular economy in e-waste management

Since 2012, when Ellen MacArthur Foundation [9] has proposed for the first time the model of circular economy for a proper solid waste management, the minimization of primary raw material consumption has been evaluated considering the principles of this procedure. The circular economy concept is defined as an economy that is restorative and regenerative by design with the aim to keep the object of interests at its highest utility and value at all times. This economy is based on the following principles: repairing (fixing fault but with no guarantee), reusing (simple reuse without any modifications), refurbishing (aesthetic improvement with limited functionality improvements), reconditioning (potential adjustments to the item to bring it back to working order), recycling (extraction of raw material for use in new products) and remanufacturing (series of manufacturing steps acting on end-of-life part of product to produce as-new, better performing products with warranty). A good example of illustration for this procedure principle is shown in Figure 1.

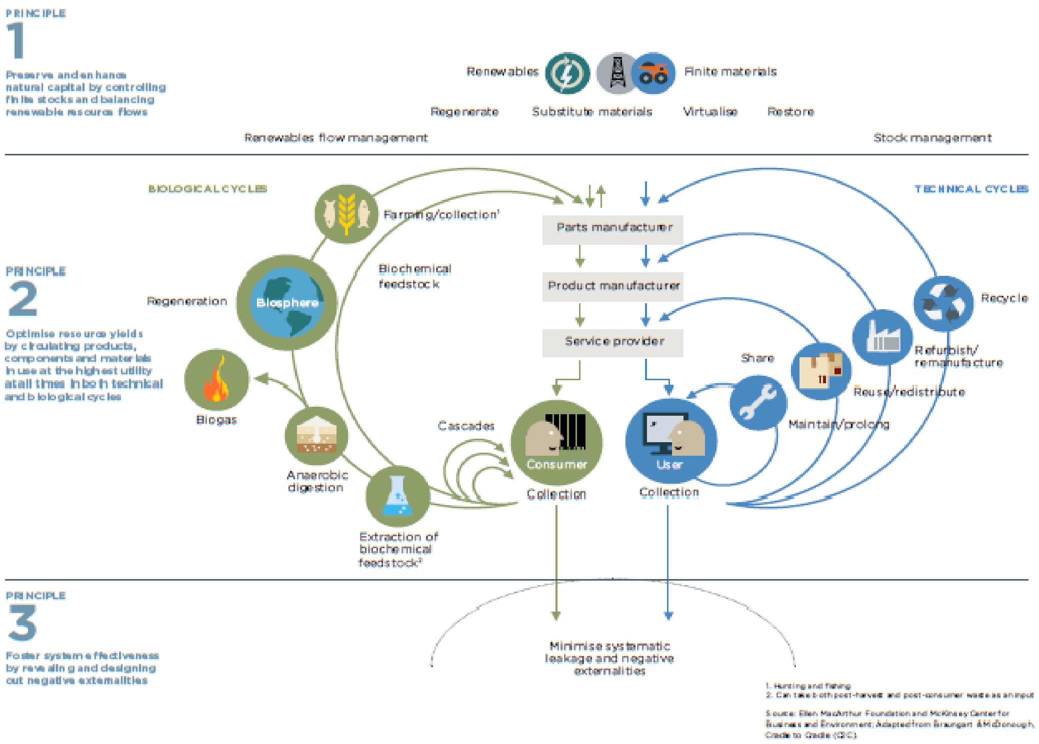

Figure 1 Outline of a circular economy [9]

By applying this concept, valuables thoughts on waste eliminations, decrease of primary resource dependency and increasing resilience are encouraged. In order to realize this concept, beside the actual models of impact assessment (Material Flow Analysis (MFA), Life Cycle Assessment (LCA) and its various extensions, Life Cycle Sustainability Assessment (LCSA), Environmentally Extended Input - Output Analysis (EEIO), and Cost Benefit Analysis (CBA)), a new methodology has been proposed by Iacovidou et al [10]. This is represented in Figure 2.

According to the authors the CVORR methodology is stringently necessary for a close sustainability and to increasing resilience for the circular economy. In addition, this has the advantage of realizing the foundations for the future advances in computational and assessment methodologies in the field of resource recovery from waste.

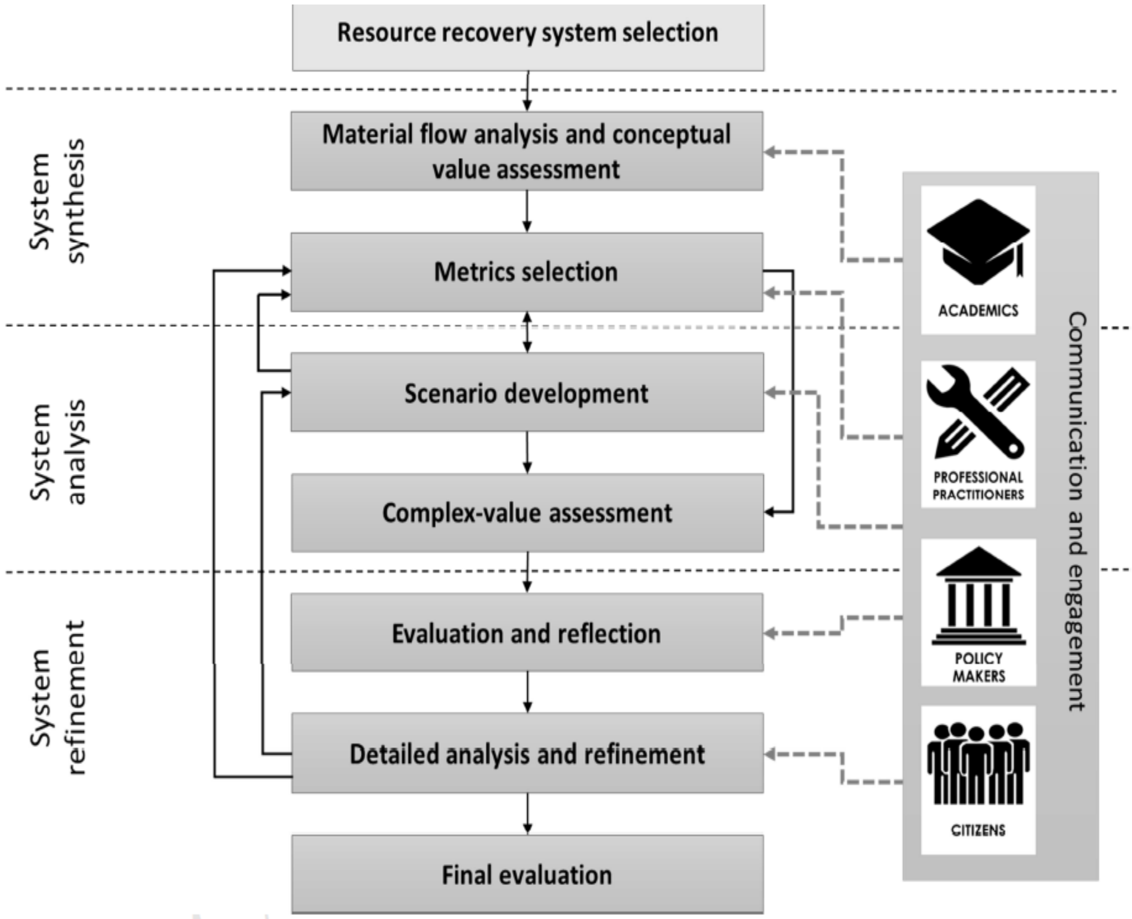

Figure 2 Framework for the complex value optimization for resource recovery (CVORR) [10]

3 Dimensional Printing /Additive Manufacturing/Rapid Prototyping

The stereolithography, the first printing process which has allowed the formation of a three dimensional object by a digital data, has been invented by Charles Hull. This method is used to create a 3 dimension object from a picture and also allows to users to test a design before studying to a larger manufacturing scale. This 3 dimensional printing technology has been developed in 1987 [11]. However, this was mostly used only within the last decade. The principle of this technology is similar with the principle of the regular inkjet printers, with the difference that they use materials for building 3 dimensional objects. Various raw materials can be used by different 3-D printing methods, including polymers, epoxy resins, nylon, wax, powders, oils, and nutrients, as well as titanium, sterling silver, stainless steel, leather, sandstone, and materials that mimic human cells [12].This technology can be devised in 7 sub-technology (Figure 3). As can be noticed, for metals there are a few 3D Printing sub-technologies that can be applied. These present better advantages beside the actual or traditional methods of manufacturing. Between these, the achievement of a better degree of design and manufacturing flexibility are of highly importance. However, in order to achieve good properties for the metallic products, the additive manufacturing technology can be used just for several metals and alloys. In addition, the metals used for this procedure must be in the powder form. In order to achieve these powders varies technologies can be applied. However, as the quality of the powders determine also the quality of the finite product, a high attention must to be given to the way of powders preparation. The best available technologies are the mechanical alloying and gas atomization. Both of them ensure the achievement of very fine, smoother and randomly particles. The gas atomization is more advantageous as it require a much more lower energy consumption as no additional pulsing or agitation during the manufacturing process is necessary.

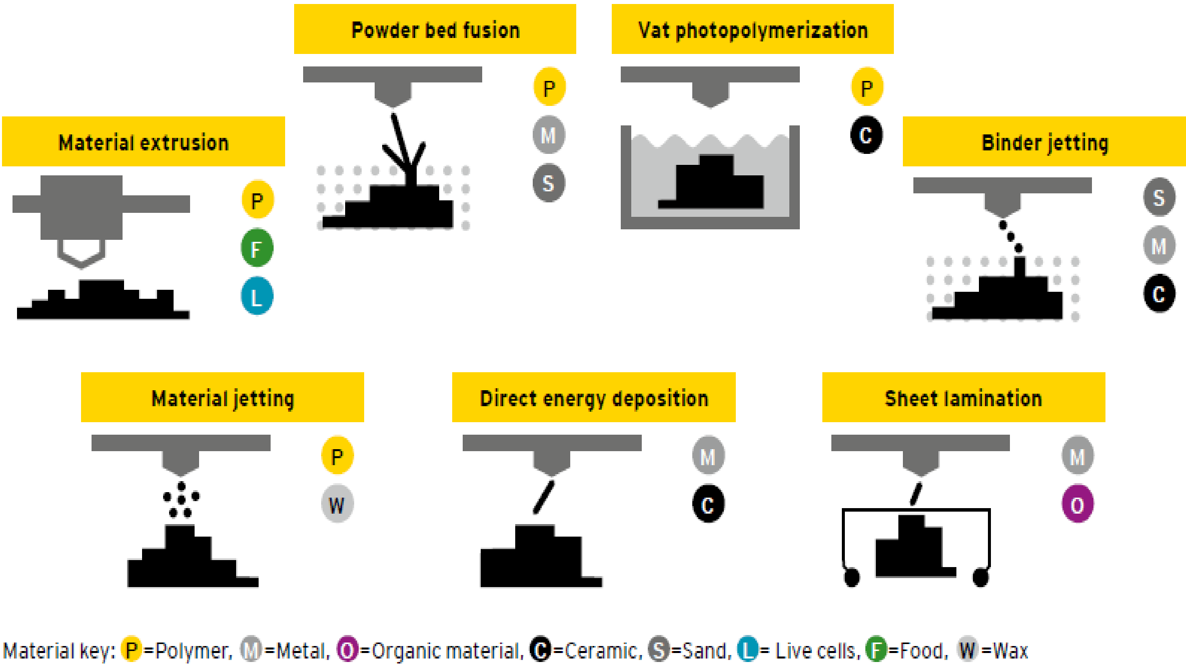

Figure 3. 3D Printing sub-technologies [13]

Currently, there are various field of application of additive manufacturing process with metals. For example, the relatively new area of 3D-printed electronics is expected to increase the use of silver and gold "inks" for the manufacturing of printed circuit boards. As this technology is very fast, according to Siemens, if this technology will be largely applied, it will generate a speed of production of 400% within the next five years with a 50% reduction of the cost [14].

4 Fenix EU project

Within this project, the experience of 9 research institutions and small enterprises (AUSTRIAN SOCIETY FOR SYSTEMS ENGINEERING AND AUTOMATION (SAT) – AUSTRIA; POLITECNICO DI MILANO (POLIMI) – ITALY; UNIVERSITA' DEGLI STUDI DELL'AQUILA (UNIVAQ) – ITALY; FUNDACIO' PRIVADA CENTRE CIM (FCIM) – SPAIN; BALANCE TECHNOLOGY CONSULTING (BAL) – GERMANY; SINGULARLOGIC (SINGULAR) – GREECE; GREENTRONICS (GREEN) – ROMANIA; NAFPIGOS MIXANOLOGOS MIXANICOS (I3DU) – GREECE; MBN NANOMATERIALIA (MBN) – ITALY) are united to achieve a circular economy in e-waste treatment. The activity will start with wastes collection, then will be continued with physical processing, recycling, recovery, and finally materials reutilization for new products production. Once the all the optimal conditions will be achieved at laboratory scale level, a small mobile or pilot plant will be designed to demonstrate all the procedures at a larger scale.

After collection, disassembling and physical mechanical treatment of waste printed circuit boards and spent Li-ion batteries, a bio-hydrometallurgical procedure will be applied to achieve the recovery of Au, Ag, Cu, Sn, Ni, Co, Al and plastic materials. In our previous project (HydroWEEE Demo Project) there have been developed hydrometallurgical procedures for the processing of various e-wastes (spent lamps, spent X-ray cathode tube, LCD, spent Li-ion batteries and waste printed circuit boards). For the waste printed circuit boards, as is shown in Figure 4, after performing of various research activities [15–19], a simple and innovative technology with high recovery yields and good purity degree of final products have been achieved.

However, in order to improve the economy of the process and also to use more environmental friendly reagents, a new technology has been proposed for this project. The concept of this recovery procedure is shown in Figure 5.

The resulted products consisted of pure metallic or oxide elements will be further used as material for the production of metallic powders, 3D printing filaments and jewelleries. In addition, comparative tests with pure element use for the above said products will be also performed.

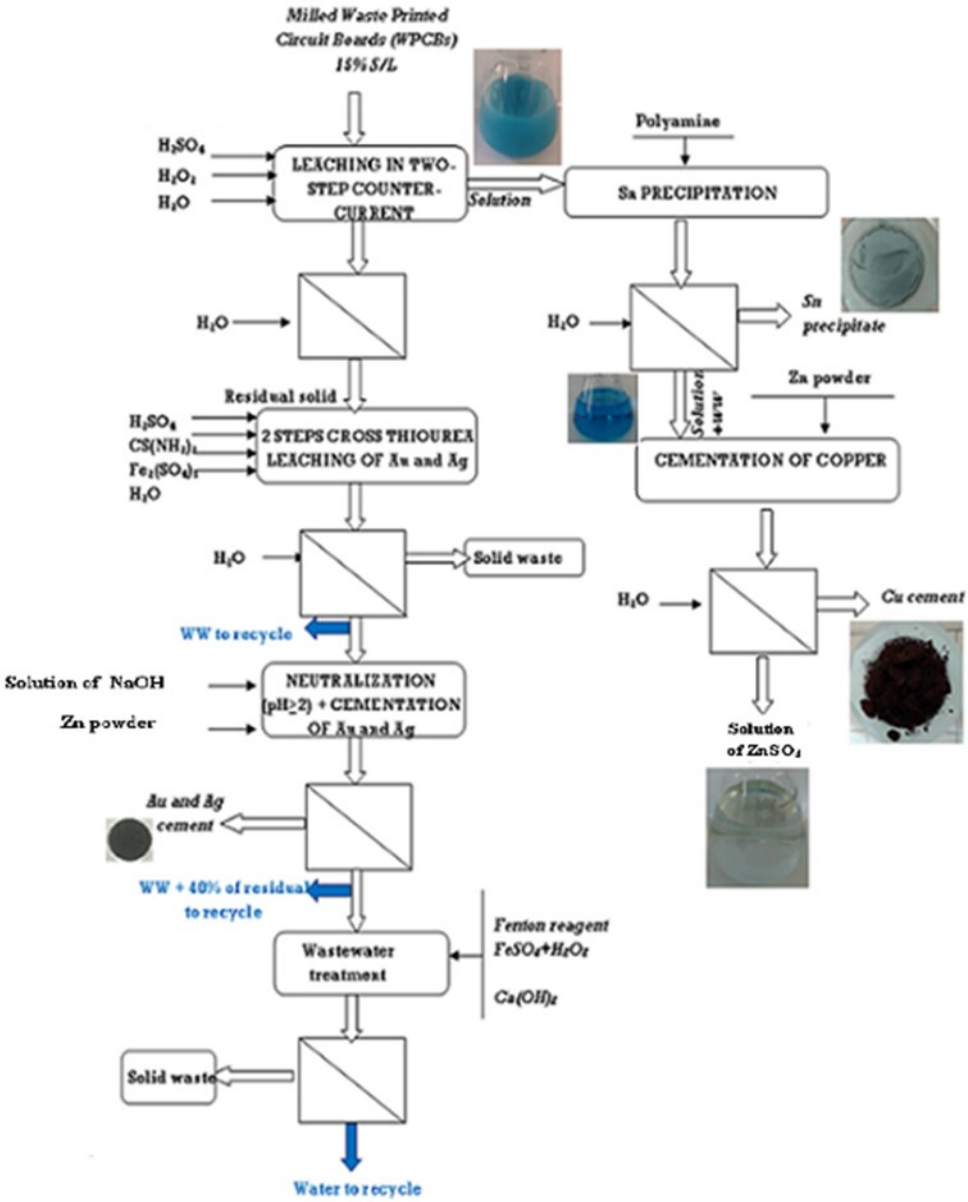

Figure 4 Hydrometallurgical process for WPCB treatment

5. Conclusions

Precious and base metals recovery for e-waste has been a main concern for worldwide research institutions and not only. Development of an appropriate technology for these waste treatment will lead to achievement of both environmental and economic benefits. Therefore, a closed loop technology where the precious and base metals are recovered from e-waste by hydrometallurgical processes and further reused for manufacturing of new products by 3 Design Printing technology is proposed within the Fenix European Project. In this way, the approach of circular economy will be implemented.

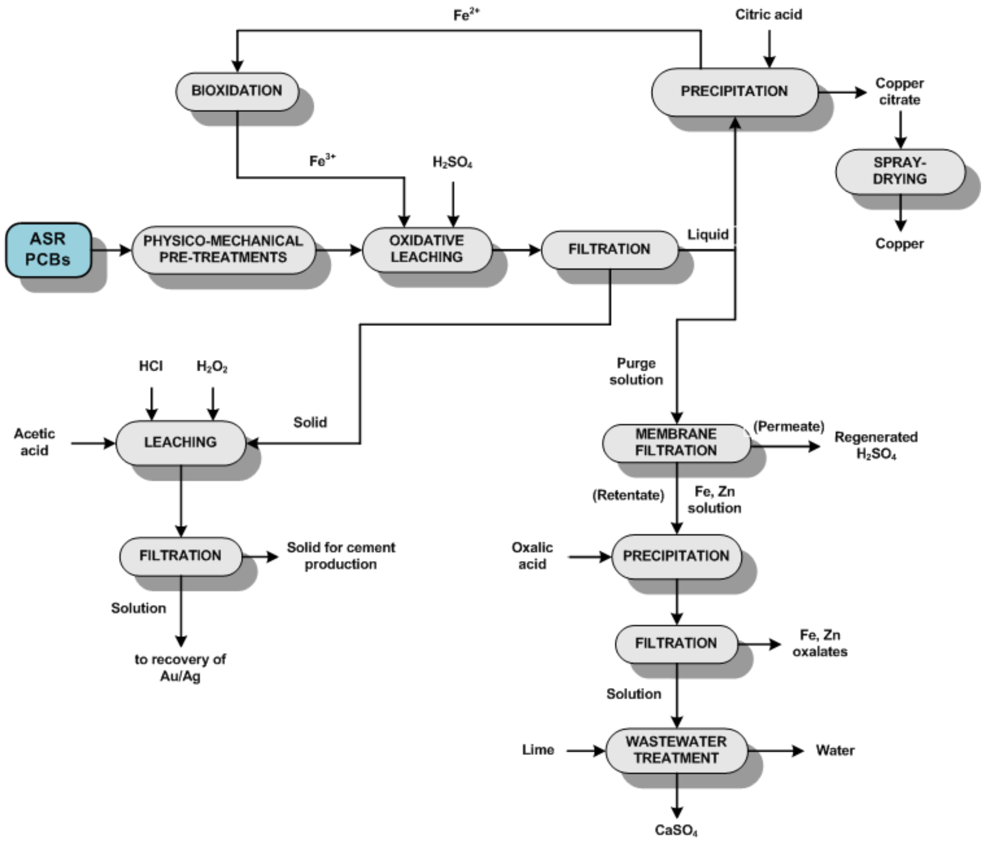

Figure 5 Descriptive flowchart of the materials recovery process within Fenix Project

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