# THE CONCEPT OF THE PROJECT HYDROPCB: AN INTEGRATED METHOD OF HYDROMETALLURGICAL METAL RECOVERY AND BIOLOGICAL WASTE WATER TREATMENT TOWARDS ZERO DISCHARGE.

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SUMMARY: The Waste Electrical and Electronic Equipment (WEEE) are produced worldwide 2-3 times faster than any other waste category [1]. Printed circuit boards (PCBs) are the most valuable parts of WEEE and are classified under “Information and telecommunications equipment” [2, 3]. Most of electronic products include more than one PCB. The total quantity of metals in PCBs, including Cu, Ag, Au, Sn, etc., often reaches 20% w/w. In other EU countries, a new sector of metallurgy is already developed aiming at recovering these metals mainly based on pyrometallurgy. Nevertheless, hydrometallurgy provides interesting perspectives over pyrometallurgy as it is less energy intensive and more environmentally friendly. Moreover, it is more cost-efficient for low-capacity plants. The latter is important for the domestic industry from an economic point of view as it allows the recovery of metals from companies that collect and separate PCBs.

In this paper is presented the concept of the project HYDROPCB on the hydrometallurgical treatment of PCBs for the extraction of valuable metals. The project has been selected for funding by the Greek General Secretariat for Research and Technology (European Union, European Regional Development Fund, ESPA, Partnership Agreement, 2014-2020, EPAnEK, 2014-2020, Operational Programme: Competitiveness, Entrepreneursphip, Innovation). It will start before the end of 2018 and will last for 3 years. The scope of the Project is the design, set up and operation of a pilot plant for the recovery of Cu, Ag, Au and Sn from PCBs via hydrometallurgical processes. Wastewater treatment for the removal of soluble metals by biotechnological process will be also implemented on pilot scale for first time in Greece. The unit will also include the management of solid residues with a prospective of zero waste.

BIANATT, Ecoreset and the School of Mining and Metallurgical Engineering of the National Technical University of Athens, in the frame of HYDROPCB, will develop a process in pilot scale which complies with the contemporary priority of circular economy in the sector of metals production. The School collaborates with the aforementioned Companies to contribute original

research results, which will originate from the collaboration of three different Laboratories with expertise on the topics of the current research, for the design of a flow sheet of an integrated hydrometallurgical and biotechnological treatment scheme of PCBs. The design and construction of the pilot plant will be based on this flow sheet.

## 1. INTRODUCTION

Waste Electrical and Electronic Equipment (WEEE) also referred to as UEEE (Used Electrical and Electronic Equipment) is a generic term used to cover all items of electric and electronic equipment (EEE) and its parts that have been discarded by its owner as waste without the intend of reuse. According to the WEEE Directive 2012/19/EC (European Union) WEEE are defined as a category of waste consisting of equipment at the end-of-life, powered by electricity or through electromagnetic fields and designed for use in a voltage typically not exceeding 1000 V AC and 1500 V DC.

WEEE belongs to the fastest growing waste stream in the world, with an increase from 33.8 million metric tonnes (Mt) in 2010 to 41.8 Mt in 2014 and an amount of about 50 Mt in 2018. The main driving forces of such a trend are explained by the increase of the world population, the rapid socio-economic development with facilitated access to modern technologies, the change in consumer patterns and the rapid technological advancement (consumers upgrade their mobile phones after about 2 years in US and EU).

Most electronic products contain one or more PCBs. Their size and composition depend on the application, with PCBs in communication devices, for example, laptops, smartphones, etc. containing a wide range of metals. Important metals are found in the actual board (the copper patterning), the electronic parts, the contacts, soldering, and the protective coatings. The main incentives in PCBs recycling are the recovery of copper and precious metals. Mobile phones contain the highest amounts of precious metals. It was estimated that a 110 g smartphone (without the battery) contains approximately 305 mg silver, 30 mg gold, and 11 mg palladium, the last being at least 10 times more concentrated than in the natural ores mined [1].

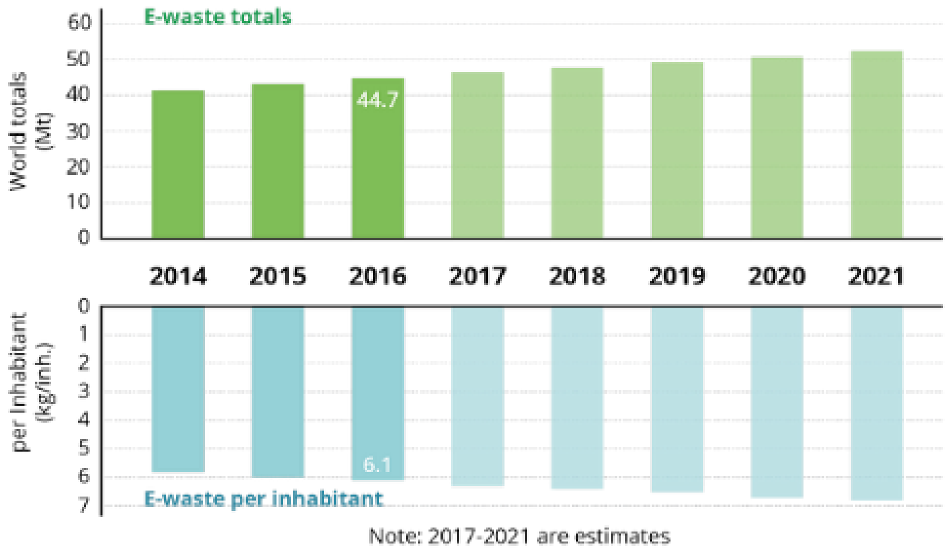


Figure 1: Global e-waste generation from 2014 to 2021 [4]

The collection and recycling of WEEE in Greece is increasing steadily. In 2006 no more than 12000 t were collected, while currently the collection to recycling reaches up to 54000 t with an increasing tendency of 4% [5]. BIANATT is collecting 100 t/y of PCBs that contain up to 23 kg Au, 110 kg Ag, 5 kg Pd, 17 t Cu and 4 t Sn. These metals can be recovered and sent back to the market with multiple benefits. The processing of PCBs in the main European plants requires transportation of this material to long distances increasing the carbon footprint of the process. Moreover, the processing of an 'artificial ore' far away from the extraction site leads to losses of income and development opportunities for the recycling plant. For all the above reasons, BIANATT ECORESET and the School of Mining and Metallurgical Engineering of NTUA designed HYDROPCB project for the development and operation in pilot scale of an integrated scheme for the recovery of Cu, Sn, Ag and Au from PCBs using low energy, environmentally friendly processes aiming at zero discharge.

The project has been selected for funding by the Greek General Secretariat for Research and Technology (European Union, European Regional Development Fund, ESPA, Partnership Agreement, 2014-2020, EPAnEK, 2014-2020, Operational Programme: Competitiveness, Entrepreneurship, Innovation) is expected to begin before the end of 2018 and will last three years.

## 2. HYDROPCB PROJECT

Big plants in Europe process PCBs pyrometallurgically as part of their total input and are located in Belgium – Umicore, Sweden – Boliden and Germany – Aurubis. In general, these processes are energy intensive and are designed for large scale applications. WEEE collected by recycling companies, in other countries, should be transported for treatment in the installations of the above companies. Main disadvantages of this practice are transportation to long distances, increasing the carbon footprint of the process, and considerable losses of income and development opportunities for domestic recycling plants [6].

In recent years, research on hydrometallurgical processes for the treatment of PCBs and other electronic wastes is carried out because they considered as advantageous alternatives to pyrometallurgical treatment. This is due to some inherent advantages associated with hydrometallurgical processing, especially for low-grade and chemically complex streams. Pyrometallurgical processes are energy intensive, and often the products that are obtained pyrometallurgically by treating WEEE require additional processing to produce pure compounds. Moreover, for low-capacity, decentralized plants hydrometallurgical processes are more flexible and can be incorporated into a general processing scheme [1].

BIANATT, Ecoreset and the School of Mining and Metallurgical Engineering of the National Technical University of Athens, in the frame of HYDROPCB, will develop a hydrometallurgical process for the recovery of Cu, Ag, Au and Sn from PCBs, in pilot scale which complies with the contemporary priority of circular economy in the sector of metals production. A schematic diagram of the project concept is presented in Figure 2.

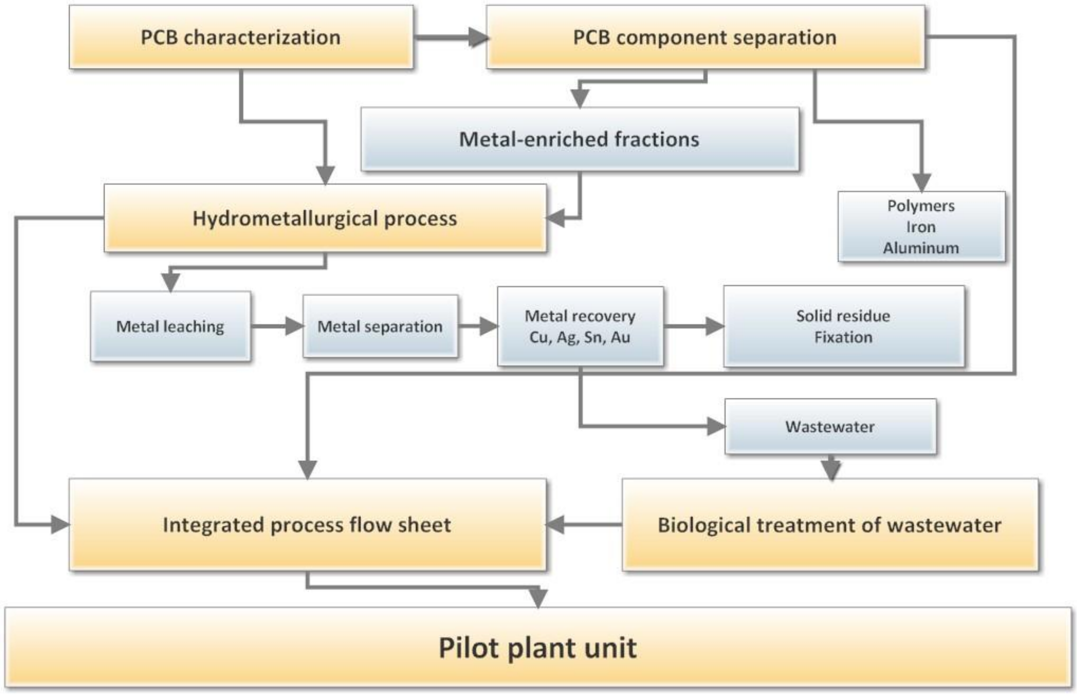


Figure 2. Schematic diagram of the concept of PCBHYDRO Project.

A brief description of main parts of the schematic diagram follows.

### 2.1. PCB component separation /Targeted metals enriched fractions.

A key step of the process development is the pretreatment of PCBs material in order to recover targeted metals with satisfactory efficiency in the steps that follow. The characterization of the materials, foreseen as a first stage (Figure 2) will provide all necessary information for that. Following characterization by different physico-chemical techniques, component separation and the necessary pre-treatment to obtain enriched fractions in targeted metals, is to be designed by the Laboratory of Minerals Processing of the School of Mining and Metallurgical Eng. of NTUA. As it will be explained in the following section, the feed of the step of metals leaching with materials of desirable properties is critical for a successful hydrometallurgical process. For example, the reduction of grains of a material will optimize metal leaching efficiency.

### 2.2. Hydrometallurgical process

A hydrometallurgical process is consisted from two main steps:

1. The transfer of metals from the solid matrix into a liquid/aqueous phase. This step is called leaching or lixiviation and often brings into solution not only the metals of interest but also undesired constituents present in the material.
2. Separation of the metals of interest from the undesired elements present in solution.

The efficiency of the leaching process is influenced by many factors: the type of leaching agent, its concentration, particle size, pH, temperature, leaching time, stirring, solid-to-liquid ratio, distribution of elements in the material, entrapment of soluble species into less soluble/insoluble particles [7]. Fast leaching kinetics at ambient temperature is desirable from an economical point of

view. Slow kinetics for undesired constituents is also an advantage. This makes selective leaching possible and leads to easier subsequent processing of feeds and to higher product purity [1].
The development of the hydrometallurgical process is the “heart” of HYDROPCB : An extensive lab scale investigation aiming at the design of the hydrometallurgical method is foreseen. It will include dissolution of the metals from the PCBs materials using different solvents. Such solvents are aqua regia, sulphuric acid with oxidants etc. Furthermore, selective separation and recovery of metals will follow with various techniques like sedimentation, extraction with organic solvents and electrolysis. The hydrometallurgical process will be designed by the Laboratory of Metallurgy-Hydrometallurgy Unit of the School of Mining and Metallurgical Eng. of NTUA.

### 2.3. Biological treatment of wastewater

Wastewater originating from mining and metallurgical industries is often acidic and typically characterized by a significant content of soluble metals, such as Fe, Zn, Cu, Ni, Pb etc. This type of wastewater is also expected to be produced from the hydrometallurgical treatment of PCBs.
Biological treatment of such wastewater is a viable option due to lower cost and better sludge properties compared to conventional chemical treatment [8, 9]. Briefly, for example, when metals are simultaneously present with sulfates, a sulfate reducing bacteria SRB bioreactor may be designed and set up for metal sequestering from waste water. In such a process, SRB obtain energy for cell synthesis and growth by coupling the oxidation of organic substrates or molecular hydrogen ($H_2$), under anaerobic conditions, to the reduction of sulphate ($SO_4^{2-}$) to sulphide ($H_2S$ and $HS^-$). Sulphide reacts with divalent metal ions which are then sequestered from wastewater as insoluble metal sulphides in the form of various mineral phases. Sulphide and bicarbonate ions, which are formed during sulphate reduction and carbon source oxidation, equilibrate into a mixture of $H_2S$, $HS^-$, $S^{2-}$, $CO_2$, $HCO_3^-$ and $CO_3^{2-}$, which buffers the solution pH around neutral to slightly alkaline values.
Other bioreactor schemes include the simultaneous sequestering of metals and nitrates and/or chloride from waste water. Based on the extensive experience and expertise on bioreactors for metals sequestering from wastewater of the Laboratory of Environmental Science and Engineering of the School of Mining and Metallurgical Eng. of NTUA, the waste water treatment scheme, to be designed for the project, will be based on the selected leaching process and the concentrations of the residual metals.

## 3. CONCLUSIONS

HYDROBCB project is based on the sustainable treatment of electronic wastes and the recovery of valuable and precious metals from PCBs complying with the contemporary priority of circular economy in the sector of metals production. Thanks to the originality of the overall concept which includes sustainable metal extraction by hydrometallurgical process and sustainable biological treatment of wastewater, together with all the necessary supporting steps, a zero discharge treatment scheme is expected to be realized in pilot scale. The consortium, composed of BIANATT, a national leader in the recycling of WEEE in Greece, together with Ecoreset and three Laboratories of the School of Mining and Metallurgical Eng, has been selected for funding by Greek General Secretariat for Research and Technology (European Union, European Regional Development Fund, ESPA, Partnership Agreement, 2014-2020, EPAnEK, 2014-2020, Operational Programme: Competitiveness, Entrepreneurship, Innovation). The project is expected to begin before the end of 2018 and will last for three years.

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