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Mobile Hydrometallurgy to recover rare and precious metals from WEEE

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Abstract: The recycling business is traditionally dominated by SMEs. In the last 5 years a general trend in the electronics recycling sector to bigger companies is very visible. Multinational, multi-sector companies are buying several smaller recyclers every year. Hence the HydroWEEE project deals with the recovery of rare and precious metals from WEEE. The idea has been to develop a mobile plant using hydrometallurgical processes to extract metals like yttrium, indium, lithium, cobalt, zinc, copper, gold, silver, nickel, lead, tin in a high purity. By making this plant mobile several SMEs can benefit from the same plant. By making the processes universal several fractions (lamps, CRTs, LCDs, printed circuit boards and Li-batteries) can be treated in the same mobile plant in batches. This reduces the minimum quantities and necessary investments. In addition these innovative HydroWEEE processes produce pure enough materials that can be directly used for electroplating and other applications.

Keywords: electronic waste, recycling, precious metals, material scarcity, rare earth, hydro-metallurgy

1. INTRODUCTION

Waste from Electrical and Electronic Equipment (WEEE) is the fastest growing waste stream in Europe. Worldwide figures are ranging from 20-50 million cubic meters e-waste. About 5% of the total waste stream can be derived from End-of-life Electr(on)ics. Therefore the EC implemented the so called WEEE Directive in order to ensure an environmental friendly treatment of end-of-life electrical and electronic equipment. In the European Union alone more than 17 million tons of electrical and electronics will become obsolete this year.

Rapid changes of consumer demands have affected that WEEE represents the fastest growing waste stream in the EU with between 3 and 5 % per year, which means that it doubles every 12-15 years. In average every three years the IT equipment is exchanged by rapid growing turnover rates. Other electr(on)ic products are exchanged in average every 5 years. The life cycle of electr(on)ics is decreasing constantly, products are exchanged faster and faster. Obsolete electr(on)ic equipment ends up as e-waste which leads more and more to a global problem: With its complex composition of materials, components and hazardous substances, it constitutes a considerable threat to the environment. About 70% of the heavy metal in landfill is directly coming from e-waste. Next to that a reproduction of electr(on)ics needs about 10 times the final weight on abiotic natural resources (especially crude oil). That means that a TV set of about 50 kilos consumed about 500 kilos of raw materials during the production phase. Hence it is clear that landfilling of e-waste is an environmental crime. Countries all over the world therefore reacted and developed a legislation which should lead to a “greening” of e-waste.

Electr(on)ic products consist of a high amount of diverse metals. According to a survey of Sullivan e.g. mobile phones have a metal content of 25 % (accumulator and recharger not included), mainly copper (Cu), iron (Fe), nickel (Ni), silver (Ag) and zinc (Zn). Though the absolute amounts of each device regarding the most valuable elements are low (16 g Cu, 0.35 g Ag, 0.0034 g Au, 0.015 g Pd, and 0.00034 g Pt) this adds up to e.g. 0.35 t of platinum based on estimated 1 billion of cell phones in 2010 (see also figure below).

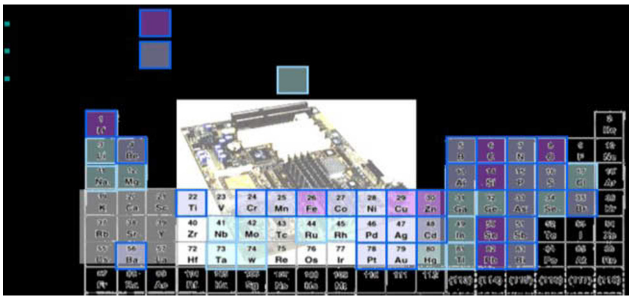

Figure 1: Elements in assembled Printed Circuit Boards

Regardless of their low amount in specific electronic components there are some metals which are highly preferred or are even essential for the present technology. The most famous example is tantalum and niobium, which is processed from the ore coltan.

In 2010 the Raw Materials Initiative of the European Commission defined 14 critical raw materials, most of rare metals (including rare earths oxide) which are used for electr(on)ic devices belong to this category.

Most electr(on)ic relevant metals are mined in only in 5 – 10 (non-European) countries, some of them in conflicting areas without "good governance".
Recycling of these "critical metals" will contribute to:
the overarching goals / objectives of the proposed project
minimizing the toxic burden on and around the sites of mining, processing and manufacturing
reducing the devastation of soil, natural habitat and other living conditions of as well human beings as endangered species of animals and plants
cost saving for manufacturing (taking into account rising prices for most of minerals and metals respectively)
downsizing the dependency of permanent supply of essential resources from some non-European countries
supporting initiatives, resolutions and legal actions of the UN, EU, OECD and national governments for saving national resources and energy towards improving environmental protection.

In addition the recycling business is traditionally dominated by SMEs. The latest data from Eurostat (2008) show for EU27 the following key data for the recycling sector:

Number of companies	14.400
% SME	80%
Turnover (in Mio €)	30.000
Value creation (in Mio €)	6.300
Employees	130.000

In the last 5 years a general trend in the electronics (including batteries and lamps) recycling sector to bigger companies is very visible. Multinational, multi-sector companies are buying several smaller recyclers every year.

This trend is mainly caused by 2 factors:

- Many countries transposed the WEEE (Waste from Electrical and Electronic Equipment) and Battery Directives in a way relying heavily on collective systems (producer responsibility organizations). These collective systems want to make their lives as easy as possible and normally contract only 2 or 3 recycling companies covering the whole country. This very much favors bigger multinational groups that are able to invest in very expensive mechanical recycling and separation machinery.
- Also the big secondary raw material processors are more interested in few big contracts instead of a lot of small contracts as this brings down their administrative costs (notification for transborder shipments, sampling, billing, …). Therefore it is close to impossible to sell materials with a high concentration of rare and precious metals (e.g. printed circuit boards) for SMEs at the moment.

2. THE RESEARCH PROJECT

Hence the previous FP7-Research for SMEs project HydroWEEE (01.03.2009 – 28.02.2012) dealt with the recovery of rare and precious metals from WEEE including lamps and spent batteries by hydrometallurgical processes. The idea has been to develop a mobile plant using hydrometallurgical processes to extract metals like yttrium, indium, lithium, cobalt, zinc, copper, gold, silver, nickel, lead, tin in a high purity (above 95%). By making this plant mobile (in a container) several SMEs can benefit from the same plant at different times and therefore limit the necessary quantities of waste as well as investments. By making the processes universal several fractions (lamps, CRTs, LCDs, printed circuit boards and Li-batteries) can be treated in the same mobile plant in batches. This reduces the minimum quantity per fraction per recycler even more. In addition these innovative HydroWEEE processes produce pure enough material that they can be directly used by end-users for electroplating and other applications. Because of this 2 levels of intermediaries from today (bigger recyclers and secondary material processors) will be bypassed. This will make the SMEs much more competitive than today and reverse the general trend to bigger companies.

In addition this will decrease the environmental impact substantially as

- on the one hand the pilot plant will be transported to the recyclers´ locations instead of shipping large quantities of materials through whole Europe as it is done today and
- on the other hand increase substantially the resource-efficiency in Europe as a lot more precious and rare material will be recycled economically and by that decrease the amount of mining as well as landfilling.

3. THE REALISATION PROJECT

In the previous research project a mobile pilot plant with a reactor size of 1 m3 has been developed that has been and still can be used for process development and optimisation. However in order to really demonstrate the stability, financial credibility and resource-efficiency of our innovative processes an industrial stationary plant as well as a full-scale mobile plant (2-3 m3 reactor) have to be built.
Finally the previously developed processes of extracting yttrium, indium, lithium, cobalt, zinc, copper, gold, silver, nickel, lead, tin will be improved even more and new processes to recover additional metals which are still in this fractions (e.g. Cerium, Platinum, Palladium, Europium, Lanthanum, Terbium, …) from WEEE or other sectors (e.g. automotive, …) as well as innovative solutions for the integrated treatment of waste water as well as solid wastes will be developed.

The objective of the currently running follow-up FP7-Environment project HydroWEEE Demo (2012-2016) is to build 2 industrial scale, real-life demonstration plants (one stationary and one mobile) in order to test the performance and prove the viability of the processes from an integrated point of view (technical, economical, operational, social) including the assessment of its risks (including health) and benefits to the society and the environment as well as remove the barriers for a wide market uptake later on.

The major differences between the 2 new plants built during this project in comparison to the existing mobile pilot plant are:

- In the stationary plant a continuous process will be used instead of a batch process which increases the throughput a lot.
- In the mobile plant the maximum size of reactors (approx. 2-3 m3) that still fit into a container will be used in order to maximise the throughput as well. Another emphasis will be put on professional feeding and unloading of the plant as well as on piping and fittings that withstand rough shocks during transport without being damaged.

For both plants the process will be highly automated with PLCs, etc. in order to decrease the personnel costs and even enable a process cycle without personnel during the night.

In addition new research and innovation will concentrate on:

1. the optimisation of the processes of extracting Yttrium, Indium, Lithium, Cobalt, Zinc, Copper, Gold, Silver, Nickel, Lead, Tin (e.g. for lamps: reaction times for leaching, filtration, precipitation settling and another filtration; solid/liquid ratio, amount of oxalic and sulphuric acids as well as calciumhydroxide, temperature, amount of washing water, roasting temperature, …);
2. new processes to recover additional metals (e.g. Platinum, Palladium, Europium, Lanthanum, Cerium, Terbium, …) from the same 5 fractions (CRT, lamps, LCDs, Li-batteries and printed circuit boards) from WEEE or other sectors (e.g. automotive and industrial catalysts) will be developed always with the aim to find physical-chemical processes suitable for SMEs and a mobile plant;
3. innovative solutions for the integrated treatment of waste water and the other solid wastes will be developed with the aim to obtain maximum re-use of water. In our basic financial analysis that we have already carried out in the previous project the disposal costs for solid and liquid waste represent 12% of the total operating costs. Because of that and the resource efficiency approach it is absolutely necessary to optimise the HydroWEEE processes even more in order to come as close to “zero waste” as possible. For example the solid waste after leaching of the CRT powder still consists of more than 50 elements with major concentrations of approximately 25% Silicon, still 14% Zinc, 14% Lead, 8% Sulfur, 5% Potassium, 4% Barium, still 2,5% Yttrium and 2% Strontium. The waste water contains still 0,51 g/l Yttrium, 0,49 g/l Zinc, 0,15 g/l Calcium and 0,0001 g/l Cadmium. Therefore also the interlinkages between the further process optimisation and the treatment of solid and liquid residues has to be further investigated.

4. THE PILOT PLANT

This HydroWEEE Demo project will also benefit a lot from the mobile pilot plant from the previous project because

- it will be used to improve some processes or fix problems without interrupting the demonstration phase (in the product-like demonstration plants) for a long time,
- it will be used as a mobile lab to convince potential customers on their site of this innovative solution and
- it will be used for continuous improvement of the processes as well as preparing special samples for potential buyers of the our resulting products.

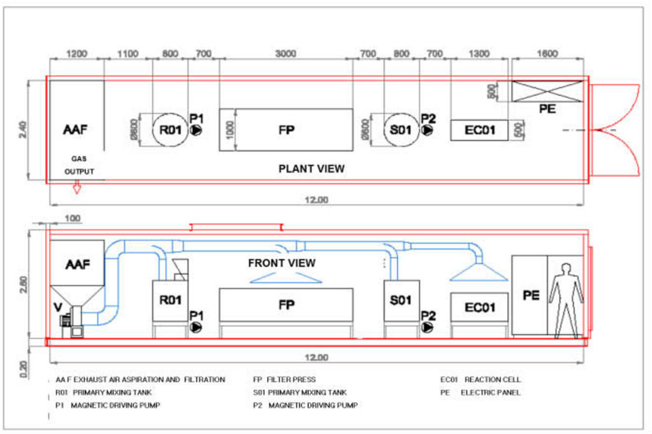

Figure 2: Mobile pilot plant scheme

Figure 3: View from the front side

Figure 4: View from the back side

Figure 5: Outside view

5. IMPACT

Emerging green technologies such as photovoltaics (PV) and solid-state lighting (SSL) do heavily depend on the use of raw materials like gallium, indium and rare-earth elements (including yttrium).

Figure 6 shows the projected growth for the two first-mentioned metals, indicating that global supply will increasingly lag behind on demand if the current circumstances pertain. The growing demand is driven by PV, SSL (notably light-emitting diodes / LEDs) and electronics (integrated circuits) for gallium and by PV and electronics (liquid crystal displays / LCDs) for indium. Meanwhile the primary production and trade of these materials is highly controlled by a few countries and particularly by China. For rare-earth elements a similar tight situation exists with global annual demand being projected to rise to 170,000–190,000 tons by 2014 and associated Chinese production of 160,000–170,000 tons being subject to export cuts. A further complication for both gallium and indium is that they are mined as by-products of other materials.

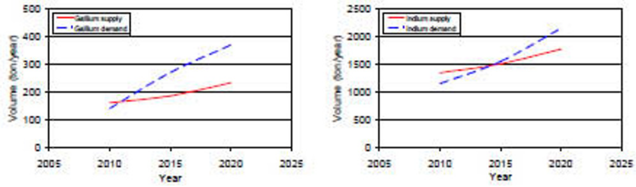

Figure 6: World-wide supply and demand forecasts for gallium (left) and indium (right)

The previous obviously poses a problem as it renders Europe particularly susceptible for the provision of these increasingly scarce materials that are crucial for meeting policies on energy renewability and energy saving (amongst others implemented in the EU ban on the incandescent bulb by 2012 and the phasing out of the halogen bulb by 2016) as well as for the further development of these sectors with apparent economical and employment implications. This is also expressed by a recent EC report of the Raw Materials Initiative and its definition of 14 economically important raw materials which are subject to a higher risk of supply interruption:

Antimony	***Indium***
Beryllium	***Magnesium***
Cobalt	*Niobium*
Fluorspar	*PGMs (Platinum Group Metals) - **platinum**, **palladium**, iridium, rhodium, ruthenium and osmium*
Gallium	*Rare earths - **yttrium**, scandium, **lanthanum** and the so-called lanthanides (**cerium**, praseodymium, neodymium, promethium, samarium, **europium**, gadolinium, **terbium**, dysprosium, holmium, rebium, thulium, ytterbium and lutetium)*
Germanium	*Tantalum*
Graphite	*Tungsten*

There are a number of reasons for this heightened supply risk. One of which is the high concentration of the production of a raw material in a given non-EU country. Other reasons are the low political-economic stability of the main supplier(s), as well as the low substitutability and low recycling rates of the raw material itself. The graphic below [Critical raw materials for the EU; report of the ad-hoc working group on defining critical raw materials; EU DG Enterprise and Industry, June 2010] presents the production concentration of the critical raw materials by source country.

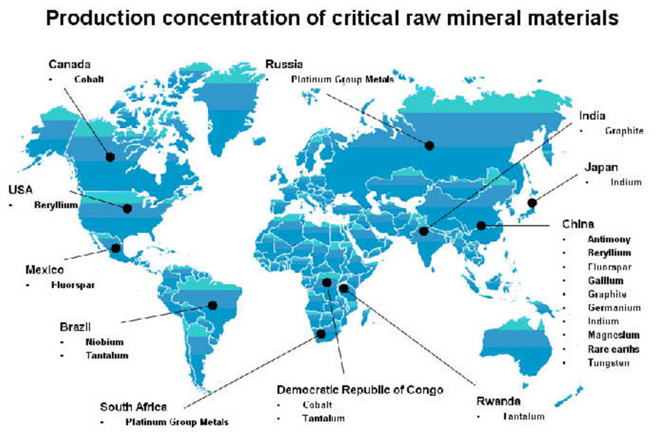

Fig. 7 Production concentration of critical raw mineral materials

HydroWEEE can extract already now 3 of those critical materials from WEEE and will expand it during this project to even more (e.g. Cerium, Platinum, Palladium, Europium, Lanthanum, Terbium, … will be in the focus).

6. CONCLUSION

With the detailed process analysis in the laboratory and the practical experience gained from the pilot plant tests it will be possible to design and build a flexible mobile plant for hydrometallurgical extraction of WEEE in the coming year. Both plants (stationary and mobile) will be fully operational before summer 2014. The following demonstration activities will give useful indications about this new approach to the WEEE recycling business.

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