

Recovery of precious (Au, Ag, Pd, Pt) and other Metals by e-scrap processing

S. B. Dimitrijević¹, Ml. B. Mirić², Vl. K. Trujić¹, B. N. Madić¹, St. P. Dimitrijević³

¹ Mining and Metallurgy Institute Bor, Zelene bulevar 35, Bor, Serbia

² Directorate of Measures and Precious Metals, Mike Alasa 14, Beograd, Department of the control subjects in precious metals, Generala Boze Jankovica 32, Niš, Serbia

³ Innovation center of the Faculty of Technology and Metallurgy, University of Belgrade, Karnegijeva 4, Belgrade, Serbia

Received July 2, 2013; Revised October 10, 2013

The professional paper is a brief report of an investigation results to be adopted into production. In fact it is a resume of a study on the idea of e-scrap processing and metal production in Mining and Metallurgy Institute Bor, Serbia, based on its expert team investigations of the relevant literature and practice evidences and own research results. The investigations results are presented shortly in the First part of the paper where the chosen technological solution is described including the basic parameters for economic analysis. The second part of the paper is a resume of the economic analysis that approves benefits of the e-scrap processing and profitability of the metals production. Conclusion signifies the investigations and the study importance for realization of a project expected to generate important ecological and economical benefits.

Key words: e-scrap processing; Au; Ag; Pd; metal production; investigation; technology; economy.

INTRODUCTION

E-scrap processing of based metal production in Mining and Metallurgy Institute Bor, Serbia is a project based on serious considerations of the actual trends in related technology and economy fields. As an (Research and Development) R&D institution, we have adequate experience, staff and equipment for the processing and profitability production.

As the e-scrap is one of the growing global ecological problems and its processing is in the focus of the researchers and others interested in the problem solution all over the world. Growing electronic industry production in the last decades caused the e-scrap quantity increase. E-scrap contains number of different metals such as copper, zinc, iron, precious metals, cadmium, lead, mercury and other materials such as plastics, glass and organic materials [1, 2]. Some of the metals are well marketable according to its prices trends [3] and the metal production based on e-scrap processing appears to be profitable.

According to the actual reports e-scrap quantity has been gradually rising at the annually rate of 3-5% which means 10-50 billion tones every year [4]. Global recycling rate of e-scrap is variable: while it is 86% in Japan, 50-60% in EU and 12-13% only in Serbia [5]. To raise the e-scrap recycling rate in

Serbia it is necessary to organize it better from the initial phase of gathering and sorting to the final processing and supporting activities. It is also important to organize it in accordance with the European Union legislation. Aiming that, Serbian Government has adopted the Law on Waste Management and the Law on Packaging and Waste Packaging [6]. Required framework for the e-scrap management in Serbia including its gathering and processing has been established.

In the aim to keep step with the actual trends and the situation in the field, Mining and Metallurgy Institute Bor, with its reach R&D experiences, qualified staff and equipments capacities (Figure 1), has undertook approximate investigations and framed the project of e-scrap processing and metal production as a part of its medium-term development plan. The project is planned to be realized and is expected to be important from both economical and ecological aspects.

E-SCRAP PROCESSING AND METAL PRODUCTION TECHNOLOGY

Pilot Plant Equipment.

All tests were performed in pilot plant presented on Figure 1.

Description of the Accepted Technology

Printed Circuit Board – PCB as the basic row for the special metal production was analyzed first. Chemical composition of PCB is shown in Table 1.

* To whom all correspondence should be sent:
E-mail: mladenmiriczulu@gmail.com

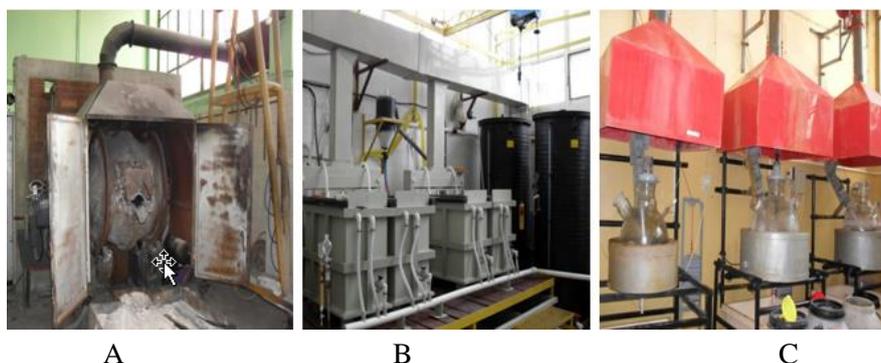


Fig. 1. Pilot plant equipment: a) Electrolytic arc furnace; b) Plant for electrolytic refining of copper;c) Glass reactor for dissolving

Table 1. Chemical composition of PCB

Element	%	Element	%	Element	%
Ag	0.014	Cr	0.001	Mg	0.0141
Cu	22.601	Ba	0.008	Cd	6.79x10 ⁻⁶
Sn	3.713	Si	0.015	As	0.0019
Pb	1.342	Mo	0.0002	Ag	0.0158
Ni	0.242	Zr	0.002	Ti	0.0073
Au	0.0068	Sr	0.0003	Se	0.00034
Mn	0.003	Co	0.0014	Fe	0.91
Sb	0.019	Al	0.0082	Zn	1.86
Cr	0.001	Mg	0.0141	Ca	0.11
Ba	0.008	Cd	6.79x10 ⁻⁶	Insoluble residue	69.104

Our investigations of seven types of PCB have led to the following conclusion: the average metal part of the PCB content is 28.6% including the copper dominating 22.6%. Precious metals content was considered as the most important for their share in the market value of the metal production was estimated to be 65-80%.

Technological process of the computer e-scrap recycling starts with the following phases:

- Used computer equipment transportation
- Computer equipment acceptance
- Computer equipment storage

The process continues with the phase of disassembling of the components that includes:

- Probiy and functionality check
- Disassembly
- Separation
- Temporary storage of components, recyclable and non recyclable
- Some components transportation for further processing and/or refuse

The PCB processing is the most complex phase of the technological process for its complex composition meaning variety of materials. The processing phase includes the processes of

pyrometallurgy, electrolysis and refinement shortly described below.

Pyrometallurgy

In the preparation phase it is necessary to remove the capacitors containing very harmful and toxic materials. After grinding to the required grain size and separation of plastic, first follows magnetic separation and then separation of aluminum parts. Lead and tin in solder are very harmful for the further processing, especially in the electrolytic refining of copper. These metals must be removed by low-temperature heating process (320–350°C). Melting and casting of copper anode containing collected precious metals was performed in the Electric arc furnace-Birlac (Figure 1a) by conventional techniques for copper.

Electrolytic refining

Electrolytic refining of anodes, obtained by melting e-scrap was performed in two cathode periods in new pilot plant for electrolytic refining of anode with non-standard chemical composition (Figure 1b) in the aim to obtain copper cathodes of the commercial quality (99.99% Cu). The anode sludge is subject to further hydrometallurgical processes in order to obtain precious metals of commercial quality.

Refinement

The anode slime obtained by electrolytic refinement of the copper anodes with high content of precious metals was processed in the Laboratory for refinement of precious metals in the special 100 dm³ glass reactors (Figure 1c). The first phase of the refinement is the process of decopperisation of anode slime by leaching with diluted sulfuric acid in the presence of oxygen as the oxidant. After the process of decopperisation, the anode slime contains max. 2% of copper. Anode slime without copper is a raw material for the next stages of processes in the aim to obtaining gold, silver and palladium.

Two illustrations of the described processing technology are presented on the following figures. On Figure 2 is shown technology block scheme proposed by Park and Fray [7] and on Figure 3 adopted technology in Mining and Metallurgy Institute Bor.

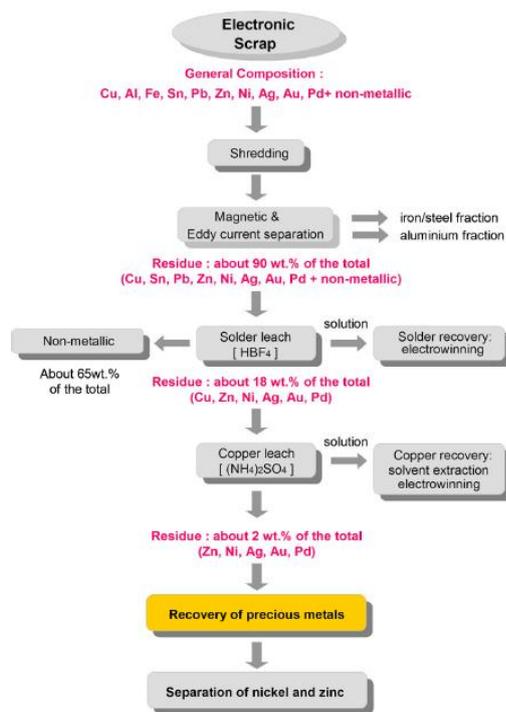


Fig. 2. E-scrap processing and metal production technology block scheme [7]

TECHNOLOGICAL PARAMETERS RELEVANT FOR ECONOMIC ANALYSIS

Pyrometallurgy

Expected electronic waste quantity or PCBs to be processed is 16 t per year.

After the separation of metal and non metal part of the PCBs the metal part containing, 1.8 t of copper is subject of the pyrometallurgical process.

During the pyrometallurgical treatment certain metals losses are inevitable (Zn and Pb mainly). These metals evaporate with the melting gases or, eventually, through the slag. The melting losses of the metals are about 2.5%. After the melting phase 11.5 t of copper anodes (11.8×0.975) contains 11.2 t of copper and 0.3t of precious metals with impurities.

Metal recovery by the hydrometallurgical treatment of metal parts is: for copper ≈ 99%, for gold ≈ 98%, for silver ≈ 93% and for palladium ≈ 98%. This means that electrolysis will have at disposal: 11.0/12 = 0.92 t of anodes per month, while the average weight of anodes will be 958/28 = 32.86 kg. (28 anodes is the electrolysis capacity, which annually is 336 anodes) [8].

Electrolysis

After melting and casting the electrolysis is provided with 11 tons of anodes, with 95% Cu-10.45 t.

The content of precious metals in the anodes is: max 0.1% - 0.011 t, respectively: Au: 3.183 kg, Ag: 7.7616 kg. Impurities (Pb, Sn, Zn, Fe): 4% - 0.44 t.

The process of electrolysis will result in the loss of certain metals, roughly 9%. The metal recovery in the electrolytic process will be: for Cu: 95%, for Ag: 97% and for Au: 98%.

After the electrolytic refining the following masses are obtained:

- 9.9275 t - 9.9 t of copper cathodes (as the final product)
- 550 kg of anode slime containing 275 kg of Cu, 7.529 kg of Ag and 3.12 kg of Au.
- 270 kg impurities (Pb, Sn, Zn, and Fe) distributed in the anode slime and partly in the electrolyte.

After the electrolytic refinement of the anodes the obtained slime (550 kg) is to be set copper free to the copper content in the sludge of 2% for the further precious metals refining [9].

Refinement

Copper free anode sludge of 275.00 kg contains the following amount of precious metals:

- 3130.00 g Au
- 8215.00 g Ag
- 900.00 g Pd

With the following adopted recovery of precious metals (based on laboratory experiments): 99% for gold, 98% for silver and 96% for palladium the final products quantities per year are:

- 3100.00 g Au
- 8050.00 g Ag
- 860.00 g Pd [8, 9].

ECONOMIC ANALYSIS AND THE PROJECT EVALUATION

Market Analysis

In Serbia there is still no significant competition in the field of e-waste processing and metal production based on it. Only a few organizations has potential to be e-scrap recyclers. Finished products of this type have specific markets. Since the products are stock market subjects there are reputable and reliable buyers of these products. Established business links provide the right to believe that the main buyers of precious metals to be companies such as: Heraeus GMBH or Metalor Group Switzerland. The export mediator would be exporting company Jugotehna, Belgrade, Serbia.

The final calculation of the revenue was based on the planned selling prices of RBB – RTB Bor Company for Cu, Au and Ag [10] although the World Bank forecasts are a bit different [11]. For palladium value calculation the minimum current world market price is used [12, 13]. Thus the projected prices for the calculation of revenues are as follows: Cu - 4 600 €/t; Au - 24 000 €/kg; Ag - 360 €/kg and Pd - 12 000 €/kg. As far as the supply market is concerned the printed circuit boards, as the main raw material for this type of production, shall be procured through the existing collection centers in Serbia and the region. Procurement of normative materials will be performed mainly on the domestic market. The existing 10 kV substation would supply the production facility with electricity, water, fuel, oil and lubricants will be procured through appropriate services in accordance with the processing and production dynamics.

BASIC PARAMETERS

Production capacity, structure and value

- Copper: 10.260 t/year x 4600 €/t = 47196 €

- Gold : 3.100 kg/year x 24000 €/kg = 74400 €

- Silver: 8.050 kg/year x 360 €/kg = 2898 €

- Palladium: 0.860 kg/year x 12000 €/kg = 10750 €

Investments

Equipment 50200 €, Working capital 18290 € and Others 10642 €.

Funding

Own funds 31.49% or 24920 €; Bank loan for new equipment: 68.51% or 54212€

Capital costs

Depreciation 10%, Maintenance 5% and Insurance 0,5% of the equipment value, Interest 15%

Material and energy costs

Pyrometallurgy 4044 €, Electrolysis 7080 € and Refinement 3568 €.

Labor costs

Pyrometallurgy 5520 €, Electrolysis 14670 € and Refinement 9112 €.

Other expenses

Processing: Cu 700 €/t, Au 150 €/kg, Ag 10 €/kg, Pd 150 €/kg,

Environmental costs: 1000 €/year, Export supporting services 8% of Au and Ag income, Chemical analysis 1200 €/year, other expenses 2000 €/year.

Financial Projections and the Project Evaluation

All financial projections (Tables 2, 3, 4) for the six year period, including one year of investment and five years of production, indicate the project feasibility.

Table 2. Income Statement

	1	2	3	4	5	6	Total €
Incomes		135244	135244	135244	135244	135244	676220
1.Selling Cu		47196	47196	47196	47196	47196	235980
2.Selling Au		74400	74400	74400	74400	74400	372000
3.Selling Ag		2898	2898	2898	2898	2898	14490
4.Selling Pd		10750	10750	10750	10750	10750	53750
Costs		81507	80301	78914	77319	75484	393525
1.operational costs		73375	73375	73375	73375	73375	366875
2.Funding costs		8132	6926	5539	3944	2109	26650
Gross profit		53737	54943	56330	57925	59760	282695
Taxes		5374	5494	5633	5793	5976	28270
Net profit		48363	49449	50697	52133	53784	254426
Cumulative		48363	97812	148510	200642	254426	

Table 3. Financial cash Flow

	1	2	3	4	5	6	Total €
Total inflows	79132	135244	135244	135244	135244	160344	780452
Total outflows	79132	89901	90022	90160	90320	90503	530038
Net cash flow		45343	45222	45084	44924	69841	250414
Cumulative		45343	90565	135649	180573	250414	
Discounted with 15%		39429	34195	29643	25686	34723	163675

Table .- Economic Cash Flow

	1	2	3	4	5	6	Total €
Total inflows		135244	135244	135244	135244	160344	701320
Total outflows	79132	73729	73849	73988	74148	74331	449177
Net cash flow	-79132	61515	61395	61256	61096	86013	252143
Cumulative	-79132	-17617	43778	105034	166130	252143	
Discounted with 15%	-79132	53492	46423	40277	34932	42764	138755
Discounted with 74.2 % (IRR)	-79132	35314	20233	11589	6635	5362	0

- Income Statement indicates profit throughout the years of the production period
- Financial Cash Flow indicates permanent liquidity and continual positive net cash flows
- Economical Cash Flow indicates positive indicators of the project profitability:
 - ✓ Internal rate of return IRR = 74.20%,
 - ✓ Net present value (discounted at 15%) $NPV_{15\%} = 138\,755\text{ €}$
 - ✓ Pay back period PBP = 2 years

Final evaluation of the investment in the project of e-scrap processing and metal production is completely positive. Based on the projected technology and basic parameters the project feasibility is out of question. Even with the more pessimistic basic parameters profitability of the project would be enviable and with significant ecological benefits.

CONCLUSION

The paper presents results of e-scrap processing and metal production project. The project is expected to be realised in the Mining and Metallurgy Institute Bor special production department within the medium term development plan.

The research results were the basis for the adopted technological solution described as one of the possible processing variants. Basing on the adopted processing technology and the production

capacity the initial parameters for economic analysis were determined.

Economic analysis including short market analysis, the basic parameters and the financial projections (Income Statement, Financial Cash Flow and Economic Cash Flow) resulted with positive appraisal indicators. The analysis basic indicators, internal rate of return, net present value and payback period, approve the feasibility and profitability of the metal production based on e-scrap processing.

Beside the feasibility and the profitability the metal production based on e-scrap processing in Mining and Metallurgy Institute Bor is fully justified also from the environmental aspect. The project is expected to generate great economic and also ecological benefits not only for the investor but also for the Serbia and the Balkan region.

Acknowledgement: *This work has resulted from the Project funded by the Ministry of Education, Science and Technological Development of the Republic of Serbia, No. 34024 "Development of Technologies for Recycling of Precious, Rare and Associated Metals from Solid Waste in Serbia to High Purity Products" for which the authors on this occasion would like to thank.*

REFERENCES

1. Ž. Kamberović, M. Korać, M. Ranitidović, *Metalurgija-Journal of Metallurgy*, **17** (3), 139, (2011)
2. Ž. Kamberović, M. Korać, D. Ivšić, V. Nikolić, M. Ranitidović, *Metalurgija-Journal of Metallurgy*, **15**(4), 231, (2009)
3. S. Dimitrijević, A. Ivanović, D. Simonović, Ž. Kamberović, M. Korać.: Electrodeposition of copper and precious metals from waste sulfuric acid solution, 15th International Research TMT 2011, Prague, Czech Republic, , pp. 689-692, (2011)
4. <http://www.recyclingtoday.com/un-electronics-report.aspx> accessed in June 2010
5. <http://www.abiresearch.com/research/1004501>, accessed in June 2010
- 6.[6] Official Gazette, Republic of Serbia, 36/09, Law on Waste Management and Low on Packaging and Packaging Waste (2009)
7. Y.J. Park, D. J. Fray, *Hazardous Materials*, **164**, 1152, (2009)
8. V. Marjanović, A. Ivanović, B. Rajković, V. Cvetković-Stamenković, Scrap of Electronics, 41st International October Conference on Mining and Metallurgy, Proceedings (2009)
9. A. Ivanović, V. Stamenković, V. Marjanović: The industrial, economic, and environmental dimensions of recycling, 41st IOC on Mining and Metallurgy, Proceedings (2009)
10. www.rtb.co.rs
11. <http://go.worldbank.org/4R17TIA330>, accessed in June 2010.
12. <http://palladiumprice.org/palladium-price-per-kilo.html>, accessed in June 2010
13. www.metalprices.com, www.lme.com, www.kitconet.com , accessed in June 2010

ДОБИВАНЕ НА ЦЕННИ (Au, Ag, Pd, Pt) И ДРУГИ МЕТАЛИ ЧРЕЗ E-SCRAP ПРОЦЕС

С. Б. Димитриевић¹, Мл. Б. Мирич², Вл.К. Тружич¹, Б. Н Мадич¹, С. П, Димитриевић

¹ Минен и металургичен институт Бор, Зелени булевард № 35, Бор, Србија;

² Дирекција за измервания и ценни метали, Мике Аласа № 14, Белград, Департамент за контрол на съдържание в ценни метали, Генерал Бозе Янковица 32, Ниш, Србија

³ Център за иновации на Факултет по технологии и металургия, Белградски университет, Карнеджијева 4, Белград, Србија

Постъпила на 2 юли 2013 г.; коригирана на 10 октомври 2013 г.

(Резюме)

Настоящата професионална статия е кратък отчет на резултати от изследване, което да бъде внедрено в производствената практика. В действителност то е резюме на изследване върху идеята за e-scrap обработване и добив на метали в Минния и металургичен институт Бор, Србија, основана на резултати от проучване на съответната литература, данни от практиката и резултати от собствени изследвания. Резултатите са представени накратко в първата част на работата, където е описано избраното технологично решение, включително основните параметри на икономическия анализ. Втората част на статията е обобщение на икономическия анализ, който показва ползите на e-scrap обработването и рентабилността на процеса за добив на метали. Заклученията показват важността на изследването за реализация на проект, от който се очакват важни екологични и икономически ползи.