Market potential for industrial ash and slag waste in Primorsky Krai, Russia

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Abstract. This article addresses the issues of estimating economic benefits of ash and slag resource potential in Primorsky Krai on the example of CHPP-2, Vladivostok. The conducted research focused on chemical and ultimate composition of ash and slag waste (ASW) of heat power plants of Primorsky Krai. The research objectives were to determine the commercially valuable components and opportunities for their conversion into saleable products. The resource potential of Vladivostok CHPP-2 landfill was determined. Estimates on economic benefits of ASW conversion process were obtained.

1 Introduction

The industrial ash and slag waste, which is produced due to coal combustion at heat power plants, represent the only large-capacity waste at these enterprises. As a result of the high levels of coal-based electricity production that reach 38% of the world energy market, there are already 11 bln tonnes of industrial ash and slag waste accumulated at landfills of heat power plants. Russia has 1.7 bln tonnes of that amount (13 %), USA – 2.7 bln tonnes (23.5 %), other countries – 7.3 bln tonnes. Taking into account energy consumption of the world leading economies, the waste production rate will be escalating accordingly. For example, the estimates of the U.S. Energy Information Administration forecast the increase of the world electricity consumption by more than 70 % by 2025 [1-3]. Volumes of ash and slag wastes in various counties are represented in Fig. 1.

It is essential to note that storage and utilization of wastes are managed at power enterprises in accordance with ecological regulations of these countries. The developed countries, such as USA, Japan, Great Britain, virtually do not have landfills. As for the countries with malfunctioning ecological laws, industrial landfills are frequently the source of ecological pollution and lead to obvious damages of natural and urban ecosystems; they cause to the following:

1) dust pollution of air basin and soil surface as a result of microdispersed particles drifting long distances;

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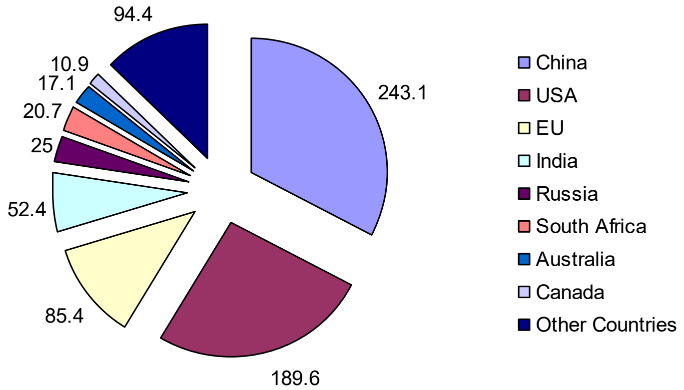


Fig. 1. Worldwide ash and slag production in 2012, bln tonnes [1].

2) pollution of surface and subterranean waters with backwaters and regenerated waters from landfills;

3) epicenters of heavy metals, etc. [4].

When it comes to utilization and recycling of power industry waste in the Russian Federation, the perception that ASW is unrecyclable is still dominant, whereas many countries see ASW as a material resource with broad spectrum of industrial application. It is vividly reflected in ASW recycling charts (Fig. 2) [5].

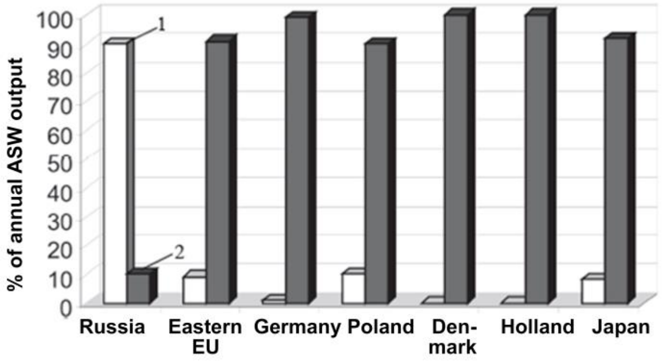


Fig. 2. ASW storage (1) and industrial use (2) at solid-fueled heat power plants in Russia, countries of Western Europe and Japan.

The main fields of ASW application can be classified as follows [6-9]:

1. As a direct substitute of natural materials in industrial, civil and road engineering;
2. During land planning, recultivation of pits, backfill of mines;
3. As fertilizers in agriculture;
4. In some cases – as a source of valuable components: aluminosilicate hollow microspheres, ferric oxide, aluminium oxide, silica, precious and rare-earth elements, etc. [4].

Historically, consumption of solid fossil fuels for the generation of heat and power dominated the fuel balance of the Russian Far East. Thus, in accordance with references [10], the portion of coal within the general structure of fuel consumption in the Far Eastern Region is 85%. In its turn, this dictates the volumes and rates of accumulation of ASW at landfills of heat power plants.

In particular, there are around 130 mln tonnes of ASW in Primorsky Krai; the annual increase of ASW volumes is 2.1-2.5 mln tonnes [6]. Over 1000 hectares of commercial lands serve as landfills. Considering that the majority of industrial landfills of power plants in the Far East are located in close proximity to or directly on the territories of settlements, the ecological pollution has negative effects for the health of people who reside nearby landfills – besides all the listed above hazardous influences. From the ecological viewpoint, immediate solution for processing of ASW has vital importance, yet in the conditions of Russian reality, unless there is instant positive benefit from reprocessing, this industry cannot expect investments. This research is aimed to determine presence or absence of economic benefits of converting ASW into salable goods and products.

2 Chemical composition of ash and slag waste. ASW treatment technologies. Resource potential of VCHPP-2

Research of ASW and development of treatment and processing technologies started at Vladivostok CHPP-2 in the 2000s. During the research process, the chemical composition of ASW produced due to combustion of various Far Eastern coals was determined (Table 1).

Table 1. Chemical composition of ASW from coals of several Far Eastern fields.

Coal field /type	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O
	%	%	%	%	%	%	%
Raychikhinskoe, B2	37	25	19	15	1,7	0,6	0,1
Rettikhovskoe, B1	53,8	23,3	7,8	9,3	2,1	2,3	0,2
Pavlovskoe	49,5	23	8	14,5	2	0,6	1
Artemovskoe	56,7	27,5	4,5	3	1,5	3,5	2,5
Kharanorskoe, B1	51	17,5	11,5	14,5	2	1,5	1
Uralskoe, G	66	24	4	2	0,5	2	0,5
Sakhalinskoe, B3	57	27	6	5,5	1,5	1	1

The influence of composition and properties of ASW was determined with regard to the opportunities of their use in production of construction materials; the production technologies for several construction materials were developed and designed all the way to the point of industrial implementation. Samples are produced (Fig. 3-6). The materials were tested, and it was proved that they meet the GOST, DIN, and ISO requirements.

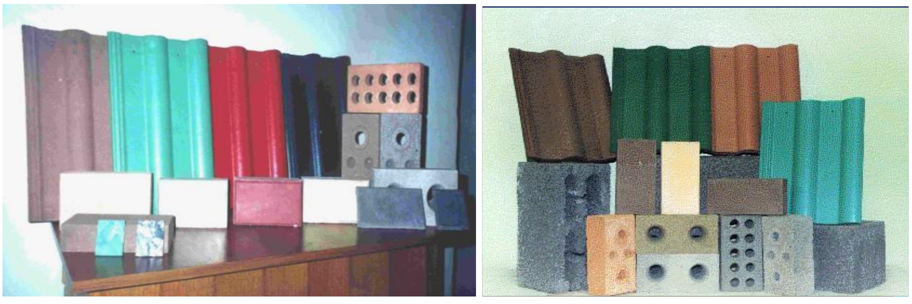


Fig. 3. Construction materials made from ASW of VCHPP-2 (ash-enrichment from 20 to 80%).

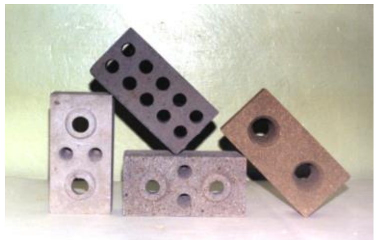


Fig. 4. Cement-ash brick made from ASW of VCHPP-2 (ash enrichment 70%, M - 75÷120).

Fig. 5. Ceramic brick made from ASW of VCHPP-2 (ash enrichment 80%, M - 120÷150).

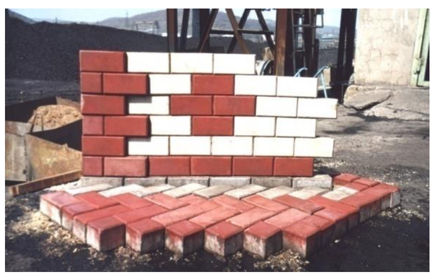


Fig. 6. Paving stone made from small-grain waste sand.

Along with development of technologies for production of construction materials, the ultimate composition of ASW at power plants of Primorsky Krai was determined with regard to rare-earth and precious metals and gold in particular (Table 2).

Table 2. Ultimate composition of ASW at CHPPs.

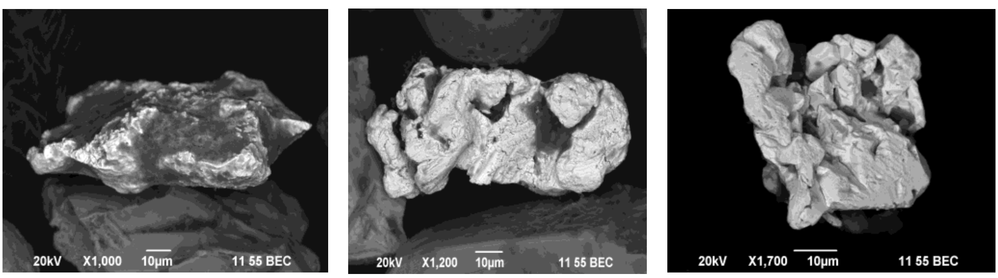
Element, g/t	Artem CHPP	Vladivostok CHPP-2	Primorye GRES	Partizansk GRES
Sc	5,0	7,0	18,0	11,0
Nb	25,2	-	10,0	18,0
Ga	40,0	49,9	28,0	33,0
W	10,0	5,0	4,5	-
Ge	3,3	4,0	1,9	3,8
V	112,0	800,0	128,0	101,0
Y	20,0	-	26,0	28,0
La	43,8	-	32,0	37,0
Ag	0,15	0,4	0,14	0,2
Li	-	50,0	54,0	84,0
Co	14,8	10,0	2,6	15,0
Ni	45,0	-	12,0	39,0
Zr	320,0	-	104,0	276,0
Au	0,2	0,1- 0,3	0,2 – 0,3	0,15
Pt	-	0,1- 0,2	0,1	-

The matrix composition of samples was determined through X-ray fluorescence analysis (XFA) via X-ray fluorescence spectrometer with full external reflectivity TXRF 8030C ("ATOMIKA", Germany). Measurements of Au, Pt, Ag content were conducted via atomic absorption spectrometer Shimadzu 6800. The method of neutron activation analysis (NAA) was used a controlling method for measuring gold content; NAA was conducted with use of equipment with radionuclide excitation source of based on 252Cf, which was developed at the Institute of Chemistry, FEB RAS.

This method was attested in accordance with GOST 41-08-205-81 and was assigned to the Category III.

Gold in technogenic waste is different due to complex morphology; it is represented with microdisperse size classes and has dendrite-like shape (Fig. 7). Petal-like, platy and needle shapes of gold grains were not detected. Significant portion of gold is tightly associated with surrounding metals, which complicates the extraction task disregarding the significant amounts; moreover, it requires special technological operations on concentrating and additional opening.

Considering chemical composition of ASW VCHPP-2, the characteristic of VCHPP-2 as of a source of some secondary raw materials (SRM) is presented (Table 3). The table shows volumes of resources accumulated and their approximate cost.



a b c

Fig. 7. Micro particles of gold extracted from ASW VCHPP-2 (taken with SEM): a – xenomorphic gold grain with mercury and silver as tramp elements 117x37 µm); b – cloddy gold grain with mercury and silver as tramp elements (94x34 µm); c – detrit-cloddy grain of neat gold (54x43 µm).

Table 3. Characteristic of VCHPP-2 as of a source of some secondary raw materials.

	Secondary raw material (SRM).	SRM concentration (g per tonne of ASW). Minimal results	Approximate amount of SRW accumulated at landfills, tonnes	SRM cost (thous. rub.)	With minimal prices	
1	Gold	0,2	6	9 000 000	1500	Rub./g.
2	Platinum *	0,2	6	9 300 000	1550	Rub./g.
3	Palladium *	0,1	3	1 800 000	600	Rub./g.
4	Scandium	7	210	75 600 000	360 000	Rub./kg.
5	Germanium	2	60	1 710 000	36 000	Rub./kg.
6	Lanthanum	26	780	1 080 000	1 350	Rub./kg.
7	Fe (in ASW - oxides)	70 000	2 100 000	42 000 000	20 000	Rub./t
8	Small-grain sand	30 000	900 000	630 000	700	Rub./t
9	Underburning	120 000	3 600 000	9 000 000	2 500	Rub./t
Total at landfill, approximately, thous. rub.				150 120 000		
Total at landfill without scandium, thous. rub.:				74 520 000		

* - technology of extraction in development

3 Market potential of ash and slag waste processing

The three-stage option for organization of ASW processing is developed based on the results of technological experiments.

The first stage – is extractive. ASW is separated into fractions, cleaned from unburning and iron oxides at this technological stage. Already at this stage, salable goods with guaranteed liquidity can be produced – high-energy fuel and its briquettes (Fig. 8-9), iron concentrate and sand (Fig. 10-11).

Fig. 8. Underburned extracted from ASW.

Fig. 9. Underburned briquettes.

Fig. 10. Iron concentrate.

Fig. 11. Purified ASW sand.

The second stage – extraction of valuable elements, including the gold-containing concentrate. This stage is included into the technological process after development of concentration and extraction methods for valuable elements.

The third stage – is the production of construction materials and goods made out of aluminosilicate residual matters (Fig. 3-6).

Preliminary calculation of economic parameters for the technological process of recycling with the following initial data is conducted:

1. Capital expenditures for the production setup, thous. rub. 250000;
2. Cost of raw materials (ASW), r/t 1;
3. ASW processing volumes, thous. t./ year 1000;
4. Goods planned for production at the starting stage of production: underburned briquettes (pg. 1, table 4); iron concentrate (pg. 2, table 4); unburned ash brick, blocks from cellated ash concrete, pave stone (pg. 3, table 4);
5. Data on costs, production volumes, earnings and gross total is represented in Table 4.

Key parameters for economic effectiveness of ASW processing with set initial data:

- with discount rate = 11% the payback period (PP) will be 5 years;
- net present value (NPV) for this period = 43 mln rub;
- internal rate of return (IRR) = 14,7%.

Table 4. Calculative data on costs, production volumes, earnings and gross total in case of 100% realization of output.

Product type	Product content in ASW %	Production volumes t/year	C/cost rub./t	Market price Primoye (Russia) rub./t	Earnings thous. rub./year	Gross total thous. rub./year
Underburned (in briquettes)	10%	100000	2000	3000	300000	100000
Iron concentrate (Fe content = 58 %)	5%	50000	700	2500	125000	90000
Construction materials	1,08%	10800	2669	14399	38430	9607
Microdisperse fraction	20%	200000	Production available after further development of reprocessing.			
Microspheres	1,0%	10000				
Concentrate of valuable elements	0,50%	5000				
Aluminosilicate residual matter with wide spectrum of application	62,4%	624200				

4 Conclusion

- For Primorsky Krai – the problem of urban pollution with ash and slag waste can be classified as local ecological crises.
- The resource potential of landfills is comparable with potential of natural fields of valuable components.
- The already developed technologies of extraction of simple components from ASW (magnetite, unburning) and production of construction materials allow to organize economically effective process of conversion.
- Extraction technologies for valuable components (gold, silver, rare earth metals) when developed to the stage of industrial implementation will allow to increase economic effectiveness of investments in ASW by 1.7-2.2 times.

Acknowledgments

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