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# PROCESSING OF AUTOMOTIVE SHREDDER RESIDUE - SIGNIFICANT CONDITION FOR SUSTAINABLE DEVELOPMENT

***Abstract:*** *There are two global concepts of End of Life Vehicles (ELV) recycling, although the common thing for them is inevitable grinding in shredder of more or less knocked down vehicles. As a result we get Automotive shredder residue (ASR), as a non-homogeneous mixture of various materials, where we have among others also those with strong negative influence upon Environmental Quality. On the odher hand ASR consist materiasl for recycling and materials for energy recovery. From that point of view, ASR is significant condition for sustainable development – in generaly. Given the average mass of ELVs, we come to quantities of ASR which range from 200 to 350 kg per vehicle. There is a number of world-wide intensive studies going on related to development of methods for re-use of ASR without environmental degrading and, but with increasing reusing of materials and energy. Currently the situation in Serbia is such that the legal regulations do not regulate treatment of ASR in the way which ensures safe environmental protection.*
***Keywords:*** *Automotive Shredder Residue, Environment, Sustainable Development*

## 1. INTRODUCTION

According Directive of European Union for End of life vehicles (ELV) [1], from 2015 no more than 10% mass of ELV will be reused for getting energy, whereas only 5% will be allowed for permanent storage.

In order to accomplish such demanding goals, numerous concept researches of systems and sub-systems for ELV recycling have been implemented world-wide. The author of this paper ran several system researches working on „ The Study of Recycling Possibilities of End of Life Passenger Cars in Grupa Zastava vozila" [2], as well as on issues whose results are shown below [3,4,5]. On the basis of researches implemented by numerous world researchers and institutions, as well as through analysis of results shown in [6] we reached the conclusion that there were two global concepts possible for defining sub-systems of ELV technological treatment. The illustration of these two concepts or scenarios is shown in Figure 1.

According to "Concept I", the technological treatment is ori device (shredder) for grinding; after grinding, one part of material goes to the market, another one goes to re-sorting, the third one goes to energy producers (for burning), and the unuseful waste goes to depositing.

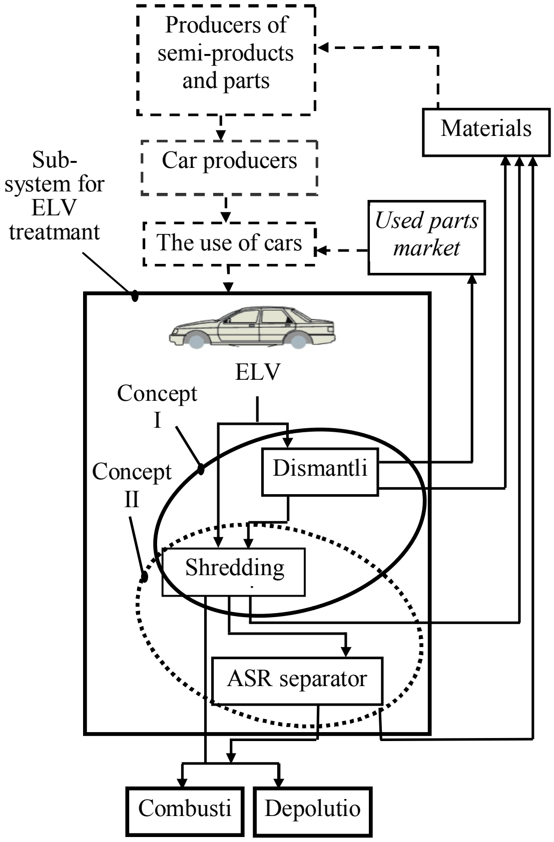


*Figure 1- Basic concepts of ELV treatment*

The main parameters for selection of concept are the costs and recycling level. It turns out that, from the aspect of costs, "Concept I" is more favourable for small and mainly medium quantities of ELV, whereas "Concept II" is better choice for continual large quantities of ELV.

The second scenario - "Concept II", is the treatment oriented towards shredder (grinding) of ELV with prior decontamination, meaning that the following basic processes are implemented: battery and fluids are removed from the vehicle; the rest of ELV (almost complete vehicle) goes to grinding; after grinding, one part of material goes to the market, the second part goes to re-sorting, the third group goes to energy producers (burning), whereas unuseful waste goes to depositing. Surely, there would be further treatment of Automotive Shredder Residue - ASR. That is the mixture which usually contains numerous various materials which affect degrading of environment if being handled without control. On the other hand, many of these materials can be returned to production cycle, as secondary raw (input) material, which represents significant saving of natural raw resources and energy.

## 2. AUTOMOTIVE SHREDDER RESIDUE - CHARACTERISTICS

In general, we get three groups of material leaving the shredder: ferrous metals (cast iron and steel), non-ferrous metals (above all, copper, aluminium and alloys of these elements) and non-homogeneous mixture of very different materials - Automotive shredder residue (ASR). Out of the mass of average ELV, as useful and for market prepared material, we get from shredder about 70% of Fe metal and about 5% of NFe metal. The quantity of ASR depends on vehicle concept, age and dismantling level of ELV, but also on the shredder plant and it ranges from 20 to 35%. It is common for the share of ASR to be - 25%. Since we know that maximum allowed quantity of unuseful waste that can be stored permanently is at most 5% of the mass of average ELV, it is clear then that ASR must undergo further treatment.

ASR mostly contains plastics (solid plastics and plastics in the form of foam), rubber, glass, wood, paper, textile, leather, sand and other impurities. In the process of magnet and air separation in the shredder it is not possible to separate fully all the quantity of metal, therefore ASR also contains metal. In this paper, we considered ASR in the case of dismantling ELV, after removing fluids and battery, only by disassembling some large recyclable parts (bumpers, fuel tank, etc.). ASR is got as shredder light fraction (SLF) at the outlet of air separator. The statement of heterogeneous composition of ASR is proven by results shown in tabel 1, which is made on the basis of analysing a number of researches. The composition of ASR is heterogeneous also from the aspect of size of material pieces, which are commonly classified as large (> 130 mm), medium-size (15 – 130 mm) and small ones (< 15 mm) [7].

From the results shown in table 1, one can conclude that all said materials, namely groups of material, are found in one of implemented researches, where we also detected plastics, metal, as well as materials of mineral origin. As for heat treatment, it is suitable that materials are homogeneous with larger content of organic components and minimum share of inert substances.

Tables 2, 3, 4 and 5 indicate the composition of ASR from the aspect of share of "primary" and "secondary" elements in the mass of shredder residue, as well as its characteristic features. The data shown below are taken from several different sources so that values of individual parameters are given as intervals. From the shown data we can see that ASR is a heterogeneous mixture and that separation of different materials for the purpose of their reuse requires complex and highly productive technologies. The composition of ASR is a decisive matter for selection of method for further treatment. How ASR is going to be further reused depends also on technological resources in relatively close environment of shredder. Eventual transport of ASR on farther distances presents a problem from the point of economy.

<table>
<tr><th rowspan="2"></th><th colspan="7">Data sources</th></tr>
<tr><th>[8]</th><th>[9]</th><th>[10]</th><th>[11]</th><th>[12]</th><th>[13]</th><th>[14]</th></tr>
<tr><td>Plastics</td><td>35</td><td>38-48</td><td>20</td><td>21,5</td><td>41</td><td rowspan="3">83,1</td><td>33</td></tr>
<tr><td>PU (foam)</td><td>16</td><td>-</td><td>-</td><td>-</td><td>-</td><td>15</td></tr>
<tr><td>Textile</td><td>13</td><td rowspan="3">4-26</td><td rowspan="3">25</td><td rowspan="3">53,7</td><td rowspan="3">10</td><td rowspan="3">10</td></tr>
<tr><td>Wood</td><td>3</td><td>-</td></tr>
<tr><td>Paper</td><td>2</td><td>-</td></tr>
<tr><td>Rubber</td><td>7</td><td rowspan="2">10-32</td><td rowspan="2">20</td><td rowspan="2">5,3</td><td rowspan="2">21</td><td rowspan="2">2,6</td><td rowspan="2">18</td></tr>
<tr><td>Elastomers</td><td>-</td></tr>
<tr><td>Paint, lacquers</td><td>-</td><td>3-10</td><td>-</td><td>-</td><td>5</td><td>-</td><td>-</td></tr>
<tr><td>Fe metal</td><td>8</td><td rowspan="3">20</td><td>-</td><td rowspan="3">8,1</td><td rowspan="3"></td><td rowspan="3">13,5</td><td rowspan="3">3</td></tr>
<tr><td>NFe metal</td><td>4</td><td>-</td></tr>
<tr><td>Wire</td><td>5</td><td>-</td></tr>
<tr><td>Glass</td><td>7</td><td rowspan="2">3-16</td><td rowspan="3">35</td><td>-</td><td rowspan="2">19</td><td>-</td><td>-</td></tr>
<tr><td>Ceramics</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Other</td><td>-</td><td>-</td><td>7,9</td><td>4</td><td>0,8</td><td>21</td></tr>
</table>

***Tabla 1- Overview of ASR composition,%***

| Element | Share % |
|---|---|
| C | 32,8 – 60,2 |
| H | 3,7 – 7,9 |
| N | 0,9 – 3,1 |
| O | 6,9 – 21,4 |
| S | 0,2 – 1,0 |
| Cl | 0,5 – 3,7 |
| Al | 0,7 – 10,5 |
| Ba | 0 -0,58 |
| Ca | 4,0 |
| Cu | 0,4 – 2,6 |
| Fe | 0,9 -18 |
| K | 0,27 |
| Mg | 0,05 – 0,87 |
| Mn | 0,036 – 0,11 |
| Na | 0,7 |
| P | 0,7 |
| Pb | 0,11 – 0,65 |
| Si | 2,1 – 9,5 |
| Ti | 0,9 |
| Zn | 0,8 - 6,1 |

***Table 2- Share of "primary" elements in ASR [15]***

| Element | Share, mg/kg |
|---|---|
| As | 2 -63 |
| Ag | < 6 |
| Br | < 20 |
| Cd | 14 -200 |
| Co | < 33 |
| Cr | 50 – 1800 |
| F | 30 -500 |
| Hg | 0,7 – 15 |
| Ni | 130 – 1500 |
| Sb | 180 -3200 |
| Se | 5,8 |
| Sn | 67 - 400 |
| V | < 150 |

***Table 3. Share of "secondary" Elements in ASR [15]***

| Other | Value |
|---|---|
| Humidity, % of mass | 0,8 – 27,3 |
| Volatile materials, % dry mase | 52,4 – 74,4 |
| Pepeo, % suve mass | 0,8 43,2 |
| BCBs, mg/kg | 1,7 – 320 |
| PAHs, mg/kg | 10 – 36 |
| PCDD/F µg/kg | 0,014 |
| Heating value, MJ/kg | 7 – 28,7 |
| Density, kg/m$^3$ | 283 - 563 |

***Table 4. Other data, features of ASR [15]***

| Material | Plastics | | | | PU foam | | Wood | Paper | Rubber | Fe | NFe metals | | Glass | Ceramics |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PVC | PP | ABS | PA | $PUf_m$ | $PUf_{pt}$ | | | | | Cu | Al | | |
| Density, g/cm$^3$ | 1,4 | 0,9 | 1,1 | 1,1 | 0,033-0,060 | 0,090-0,120 | 0,8 | 0,7 | 1,1 | 7,8 | 8,9 | 2,7 | 2,6 | 2,0 |

***Table 5. Density of material in ASR, [15,16,17,18,19]***

## 3. ASR TREATMENT METHODS

Basic ways of ASR treatment for the purpose of reuse are: mechanical treatment, burning and treament with thermal/chemical processes.

### 3.1 ASR mechanical treatment

The mechanical treatment of ASR includes several processes for separation of material and sorting by types for the purpose of re-

use. For material sorting used separators whose work is based upon two principles:

- Difference in mass, namely difference in specific density, where air streams divide lighter from harder components.
- Application of electric magnet which enables separation of magnetic (Fe) metals;

Mechanical treatment of ASR as a result get Fe metals, NFe metals and glass grains which will be delivered for the purpose of further re-use for production of products and materials. In addition, all other materials that are present in ASR will be prepared for further treatment in apropriate way.

### 3.2 ASR combustion

ASR combustion is defined as oxidation conversion for the purpose of producing heat. Table 1 indicates common content of ASR where is presence of non-burning materials, so that shredder residue may be considered as low-calorie fuel. Typical reactors for this type of fuel are such that material combustion is conducted on grids, in furnaces or on fluidized layers. For combustion of waste we usually use term "burning", because the primary target is reduction of quantity of unuseful waste, namely its volume

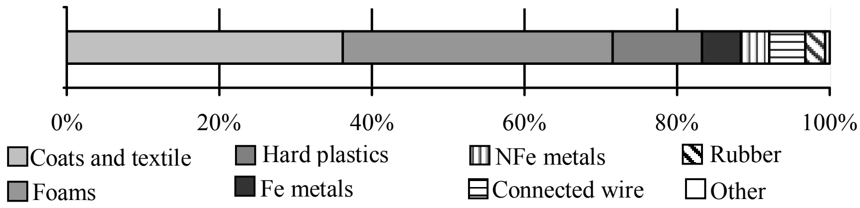


***Figure 2.Material fractions in ASR [15, 21]***

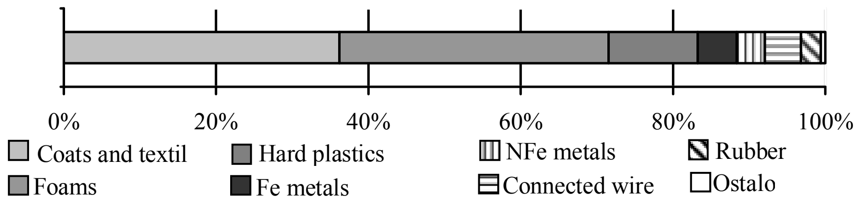


***Figure 3. Energy content in ASR and share of components [15,21]***

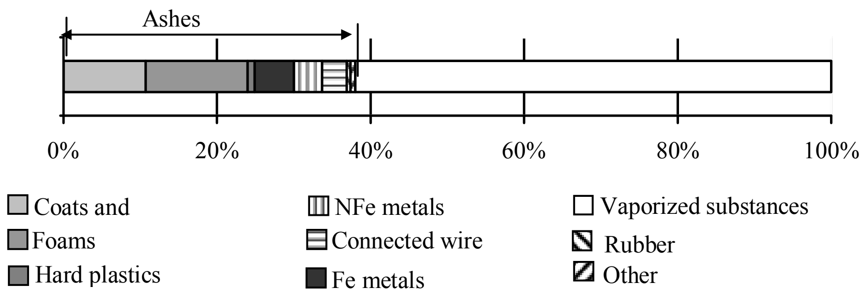


***Figure 4. Content and composition of ashes after burning of ASR [15,21]***

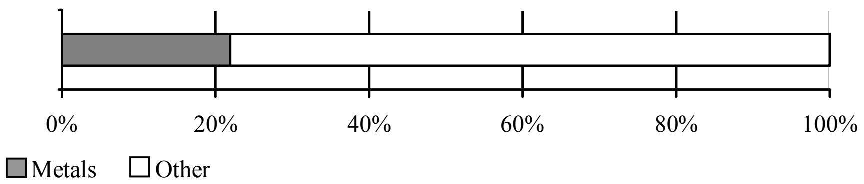


***Figure 5. Metal share in ashes content [15,21***

## 3.3 Burning of ASR mixture and community waste

The option of burning ASR mixed with community waste is still being investigated to the end of checking the possibility of optimization. Burning of ASR is surely the fastest way to dispose of this kind of waste, but with all the negative consequences related to it and listed in previous chapter. The targets for burning the mixture of ASR and municipal waste (MW) are as follows: mineralization and imobilization of inorganic fraction and destilization of organic fraction with production of heating steam within burning plant environment or use of steam for production of electrical power. Because of high content of metal and chlorine in ASR, the share of shredder residue in the mass of mixture with community waste should not exceed 10%, so that it could remain within prescribed limits for emissions from chimneys of burning plants.

There was a test conducted on the plant in Horgen (Switzerland) for the purpose of comparing the composition of slag and the chimney emission for two cases [15]:

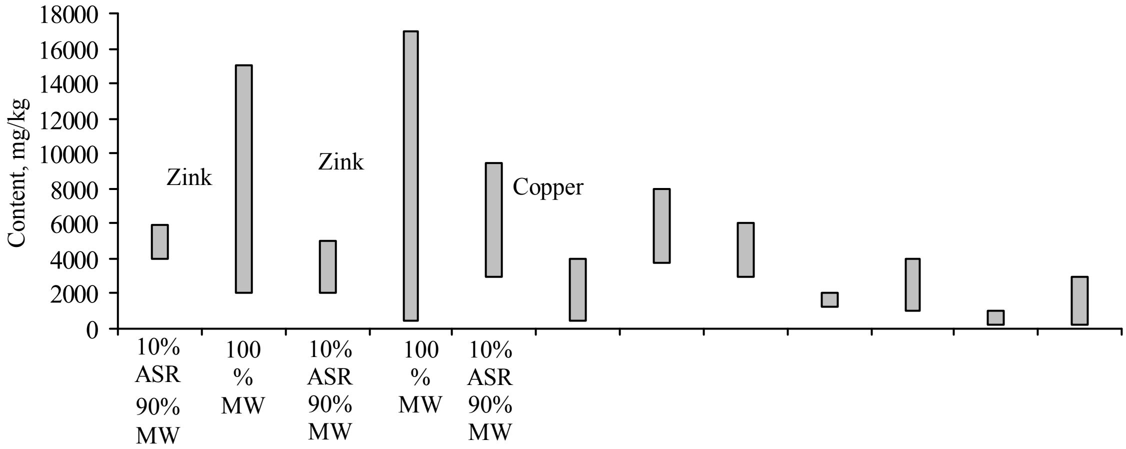


*Figure 7. Chemical components of slag [15]*

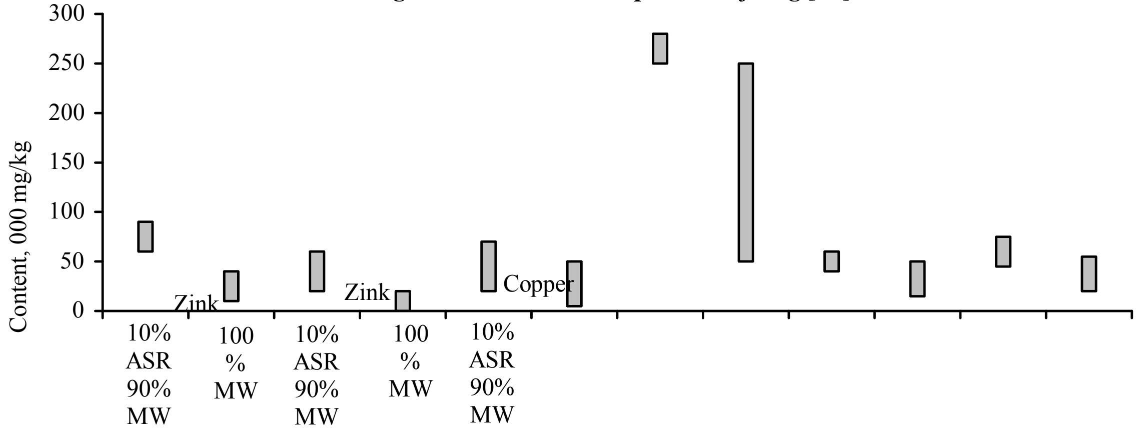


*Figure 8. Chemical components of residue generated by filtering gas coming from the chimney[15]*

- As fuel – mixture of community waste (90%) and ASR (10%);
- As fuel – only community waste;

The results of control of gas emissions from the chimney, "flying" ashes, and residues generated by filtering gas from the chimney and slag from the bottom, indicated that the content of metane, chloride and sulphor increased by adding ASR, but it remained within legal limits. Also, there was a significant increase in content of copper in slag, presence of chloride, cadmium and zink.

Figures 7 and 8 show the results of said test. We compared composition of slag and residue from chimneys in case of burning the mixture of ASR and community waste and in the case of burning community waste only. Said test indicated also the presence of concentration of polychlorinated dibenzodioxin and furan (PCDD/Fs) and polychlorinated biphenyl (PCBs) in the ashes from the boiler but within limits that are tolerated.

## 3.4 Gasification

Gasification is defined as termochemical conversion of compounds with carbon which uses gasous compounds such as water, air, oxygen and their mixtures and whose final product is gas. There are three basic types of reactors for gasification: reactors with mobile layers (ascending or descending); reactors with fluidized layers and reactors with flow withdrawal. The size of particles in these reactors (according to said sequence) ranges from 10 mm, 1 mm to 0,1 mm, whereas temperature varies from 400-500 °C to over 1500 °C. The time spent may vary from several hours to less than a second. Gasification can be done by air, steam, oxygen or their mixture. Gasification process is exothermic (in special cases it may be adiabatic) and produces gasous fuel + ash. The significant characteristic of ASR gasification process is that it does not produce polychlorinated dibenzodioxin and furan (PCDD/Fs) which is a consequence of lack of oxygen. Non-oxidized metals from burning residues can be used in the process of recycling. The volume of said gas is little in comparison with gas released from the plant chimney.

The ASR gasification process has been developed in Japan. After solidification (compaction) of ASR we get a 20-30 cm x 15 cm x 2 cm "cake" containing mostly plastics and other fuel fractions with heat value of approx. 25 MJ/kg and density of about 1200 kg/m$^3$. Throughout gasification process the volume of ASR gets reduced to less than 20% of its original volume.

Dry destillation or gasification implies that gas with temperature of 1000 - 1200 °C containing 0 – 7 % $O_2$ goes over said cakes. Gases and wet particles are burnt in secondary furnace. The time spent for one batch is 0.5 to 1 h.

## 3.5 Pyrolysis

Pyrolysis is a thermo-chemical conversion conducted by heating up in inert atmosphere (without oxygen). Depending on heating temperature, there are two types of pyrolysis: pyrolysis at "low" temperatures (400 - 600 ºC) and pyrolysis at high temperatures (500 - 800 ºC) [8]. Advantages of pyrolysis are mainly related to the fact that in these processes there are no gasous pollutants such as PCDD/Fs or NOx generated, which results from the fact there is no oxygen present. Furnace firebox is separated from the chamber with material (ASR). Heating up is done by combustion of natural gas and pyrogas generated in the process. Gaseous fraction occurring in the furnace with material (without oxygen) contains hot gas and steam. Hot gas is transferred to heat exchanger to which fresh air is supplied and after warming up it is transferred to burning chamber. Gas is released from the exchanger through the chimney out in the atmosphere. Steam is transferred to condenser where it is partially converted to fluid fraction (oil), while non-condensed gas supports heating process in burning chamber. Water, which takes heat away from steam and therefore condenses gas, can be used as energy because it heats up in that process. Undecomposed material is broke down to larger and smaller parts by sieve, and then magnet separation is conducted for the purpose of separating iron-based material.

Researches concluded [15] that total mass of ASR in the process of pyrolysis is decomposed to 21% of gas, 10% of oil, 11% of magnet materials, 25% small and 7% large residues. The solid residue after magnet separation contains fractions of raw copper, aluminium, calcium and other various inert materials.

Main components in composition of gas are as follows: $CH_4$, $H_2$, CO, $C_2H_4/C_2H_2$, and $C_2H_6$, which make about 85% of volume, whereas the rest is made of fractions such as $C_3H_6$, benzene, tuluene, butadiene and other. The measured heat value of gas is 44,7 MJ/$m^3$.

Oil can be generated in three or more densities including impurities, and used in petrochemical industry. In its chemical structure it resembles biodiesel. Roughly speaking, oil contains about 66% aromates and about 34% of aliphatic hydrocarbons with average boiling point of 258 °C. In case of oil sample generated in research [15] the density was 950 kg/$m^3$ , kinematic viscosity ~ 8 x $10^{-6}$ $m^2$/s and heat value 41 MJ/kg. The ash content was <0,01% of weight.

## 4. CONCLUSIONS

From 20% to 35% of mass of end of life passenger cars becomes Automotive shredder residue (ASR) after grinding in shredder. The quantity of ASR depends on vehicle concept, age and level of breaking down before entering shredder. ASR, as non-homogeneous mixture, mostly contains plastics (solid and in form of foam), rubber, glass, wood, paper, textile, leather, ceramics, sand and other impurities.

None of up-to-date recognized methods of ASR treatment provides reaching of target 5% of ELV mass that can be permanently deposited, which requires further optimization of treatment method by 2015. Mechanical treatment includes further procedures with non-metal components. Burning of ASR results in inacceptably large quantities of solid inert residue. Mixing and burning of ASR with community waste includes generating of hazardous substances and damaging emissions in environment. Thermo-chemical methods of treatment are still insufficiently economical.

The solution lies in further development of highly productive technologies for ASR treatment which will provide efficiency and also prevent hazardous materials and emissions from degrading environment.

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