Biomass ash and options for utilisation

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Introduction

Biomass is increasingly used for heat and power production in Europe. In 2016, the primary production of renewable energy was 211 million tons of oil equivalent (toe) within the 28 EU member states. The total quantity of renewable energy in EU-28 member states increased by about 67% between 2006 and 2016, equivalent to an average increase of 5.3% per year. Among renewable energies, the most important source in the EU-28 was wood and other solid biofuels as well as renewable wastes, accounting for 49.4% of primary renewables production in 2016 (see Figure 1) [1].

The situations of using biomass for energy are different in the EU countries regarding fuel type, boiler type and capacity. Biomass is a synonym for different types of biofuels, from the well-known wood to different types of sludge or agricultural residues like straw. The biomass use results in increasing amounts of ash which are either produced in small units leading to small amounts or in higher amounts in e.g. converted formerly coal-fired units with up to 50,000 tons of biomass ash in one plant.

The use of biomass for sustainable energy encompasses many economic, social and environmental aspects. One aspect is how to deal with the residues from biomass combustion. In the past, the utilisation of coal ashes has been developed from being a waste to a valuable secondary raw material for use in building materials, road construction and civil engineering. The challenge is to create a comparable development for biomass ashes, preferably in a shorter period. For the ash management requirements by the Industrial Emissions Directives as well as best practices for utilisation according to the Waste Hierarchy in the Waste Directive have to be considered by the producers. On the other hand technical and environmental requirements for the application of such materials have to be met and end-users need reliability in availability, quality and finally also on legal safety for use.

In this article several aspects of utilisation of biomass ashes will be discussed, especially circularity aspects, ash management and properties of biomass ashes. The results of a survey will be given on basic options for utilisation, with the status of the development. Two cases are of special interest, namely the use of ashes for nutrient recycling in the forest and as a fertilizer for agriculture.

Biomass ashes and circularity

The most popular definition of sustainability originates from the Brundtland Report of 1987, which states that: sustainable development is development that meets the needs of the present without compromising the ability of the future generations to...
meet their own needs. This encompasses both, environmental, social and economic aspects. In the national and in the EU policy, circularity is one of the ways to create a more sustainable society [2]. In the concept of a circular economy the value of products and materials is maintained as long as possible. In fact, waste generation and down cycling (Definition: process of recycling whereby the second utilization has less quality than its first utilization.) have to be avoided as much as possible. The concept of a Circular Economy distinguishes two basic cycles, namely the biological and the technological cycle [3]. The technological cycle involves the management of finite stock materials like iron, alumina, granite etc. The biological cycle involves basically renewable materials like wood and grass and includes the return of elements to the biosphere (especially return of nutrients). In a circular economy, biomass will be used according to the cascading approach. See also Figure 2. Energy conversion by combustion is mostly the last step within this cascade, whereby ashes will be generated.

Management of biomass ashes

In most cases, ashes from biomass combustion are seen as a waste, which has to be discarded.

The Waste Frame Directive [4] contains a waste hierarchy as a priority order in waste prevention and management legislation and policy (see Figure 3):

- prevention,
- preparing for re-use,
- recycling,
- other recovery, e.g. energy recovery,
- disposal.

However, from the point of view of circularity, it is proposed that recycling as part of the priority order is distinguished further:

- nutrient recycling, by returning biomass ash to the same forest where the biomass originates from,
- nutrient recycling, by returning biomass ash to the forest, but elsewhere or in agriculture,
- utilisation whereby the application is based on substitution of elements like P, K or Ca,
- utilisation whereby the application is based on other properties (as volume or grain size).

This approach pays more attention to the role of nutrients in biomass ashes and can be used in discussions about utilisation of biomass ashes.

The management of ashes from biomass combustion has to meet at least the waste priority order of the Waste Framework Directive [4]. Key themes to create a successful ash management are:

- removal of by-products from the power plants must be assured; otherwise storage capacity will be the determining factor for the operational period of a power plant. Therefore, assurance of utilisation is an important aspect. In practice, a balance will be found between financial benefits and assurance. Assurance of utilisation can be promoted by closing long-term contracts with customers and risk spreading by having different applications and/or customers.
- the by-product chain from generation at the power plant to end-user must comply with the current regulations. This applies to regulations concerning transport, waste legislation, health and safety, environment and technical aspects.
- utilisation must be sustainable.
- utilisation must generate maximum financial benefits (or minimum of costs).
- utilisation options must be accepted by society and must comply with the power brand (green power, grey power).

Properties of biomass ashes

The properties of biomass ashes depend on three main factors: the origin of biomass, the combustion process and the ash removal system. Generally, the presence of ash forming matter in biomass is based on the uptake of inorganic elements by the plant due to its need for growth. There are fifteen inorganic elements which are essential for growth in higher plants. These can be divided (based on average concentration) in primary macro nutrients (N, P, K), secondary macro nutrients (Ca, Mg, S) and micronutrients (Fe, Mn, Zn, Cu, B, Mo, Cl, Ni, Co). The macronutrients are present in concentrations of 0.2 to 5% or even higher, while micronutrient concentrations may be present at levels of 0.1 to 100 mg/kg [5]. The concentration of these elements in plants depends on several factors like the species, season of year, part of the plant and soil conditions. Furthermore, it is influenced by the way of harvesting (contamination with soil minerals), processing and pre-treatment. Due to these influence factors biomass shows a wide range of compositions. When biomass is first used for other purposes (construction wood, paper), the ash forming matter is dominated by fillers and contaminations.

Ashes from wood combustion in large scale combustion plants contain high amounts of calcium, silicon and potassium (see Table 1). The living parts of the trees (leaves, needles, twigs) contain more potassium, phosphorus and magnesium than
stem wood. Therefore, the way of harvesting (whole tree or conventional harvesting) influences the composition of the ashes (see chapter nutrient recycling in the forests). Also bark has a higher ash content and different ash composition compared to stem wood and the living parts of the trees. Ashes from combustion of agro-residues differs from wood by its very high potassium content, although specific residues like rice husks have very high silicon contents and low potassium contents. All these ashes have one parameter in common: the alumina content is very low compared to coal fly ashes. Higher alumina contents are mostly caused by contamination. Examples are contamination with soil minerals during harvesting or during first use (like waste wood and paper sludge).

A second important factor is the combustion process. The combustion temperature and residence time influences the ash formation. The higher the combustion temperature the more elements will be volatilised and are able to react with other gaseous and non-gaseous components. The boiler type determines also the volume ratio fly ash/bottom ash. Grate-fired boilers and stoves generates relatively less fly ash and more bottom ash than fluidised bed boilers and pulverised fuel boilers. At the same time these fly ashes have higher concentrations of elements like potassium, arsenic, cadmium and zinc, which are volatilised during combustion and condensates before the fly ash is removed from the flue gases. A third factor is the ash removal system, included whether bottom ashes and fly ashes are mixed together.

It can be imagined that the chemical and physical properties of biomass ashes can be highly different from source to source. This is illustrated by Table 1, which shows the concentration of macro elements and several trace elements in biomass fly ash and coal fly ash, and Figure 4, which shows the different morphology of fly ash particles from wood and coal combustion.

### Basic options for utilisation

As wood ash is one of the first human related mineral products, it can be imagined that during many centuries wood ash is used for all kind of applications like fertilizer, raw material for soap production ice remover etc. If we take a closer look there is a wide range of more or less sound applications, like use for tooth paste, egg preservation, skunk smell remover from sprayed pets etc. A survey of more serious options for utilisation of biomass ashes has been performed, using databases of international journals, interviews, internet and own research work. The results are presented in Table 2. In this survey only options are mentioned which are at least investigated on a laboratory scale with biomass ash. Investigations with coal ash are excluded.

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Unit</th>
<th>Wood</th>
<th>Wood</th>
<th>Rice husks</th>
<th>Mixed biomass</th>
<th>Coal^2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiler type</td>
<td>% m/m</td>
<td>PFB</td>
<td>GFB</td>
<td>Stove</td>
<td>FBB</td>
<td>FBB</td>
</tr>
<tr>
<td>Al&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;3&lt;/sub&gt;</td>
<td>% m/m</td>
<td>4.76</td>
<td>1.73</td>
<td>0.30</td>
<td>7.65</td>
<td>27</td>
</tr>
<tr>
<td>CaO</td>
<td>% m/m</td>
<td>29.7</td>
<td>44.5</td>
<td>0.80</td>
<td>32.8</td>
<td>4.5</td>
</tr>
<tr>
<td>Cl</td>
<td>% m/m</td>
<td>0.42</td>
<td>1.45</td>
<td>0.52</td>
<td>0.80</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Fe&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;3&lt;/sub&gt;</td>
<td>% m/m</td>
<td>2.45</td>
<td>8.41</td>
<td>0.52</td>
<td>2.04</td>
<td>7.3</td>
</tr>
<tr>
<td>K&lt;sub&gt;2&lt;/sub&gt;O</td>
<td>% m/m</td>
<td>12.3</td>
<td>16.5</td>
<td>3.29</td>
<td>2.05</td>
<td>1.6</td>
</tr>
<tr>
<td>MgO</td>
<td>% m/m</td>
<td>5.65</td>
<td>3.93</td>
<td>1.71</td>
<td>1.11</td>
<td>0.77</td>
</tr>
<tr>
<td>Na&lt;sub&gt;2&lt;/sub&gt;O</td>
<td>% m/m</td>
<td>1.19</td>
<td>0.09</td>
<td>0.87</td>
<td>0.87</td>
<td>0.6</td>
</tr>
<tr>
<td>P&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;5&lt;/sub&gt;</td>
<td>% m/m</td>
<td>2.86</td>
<td>4.97</td>
<td>1.11</td>
<td>2.70</td>
<td>0.7</td>
</tr>
<tr>
<td>SO&lt;sub&gt;3&lt;/sub&gt;</td>
<td>% m/m</td>
<td>5.78</td>
<td>18.2</td>
<td>0.47</td>
<td>27.0</td>
<td>0.7</td>
</tr>
<tr>
<td>SiO&lt;sub&gt;2&lt;/sub&gt;</td>
<td>% m/m</td>
<td>29.7</td>
<td>12.9</td>
<td>88.0</td>
<td>36.4</td>
<td>55.0</td>
</tr>
<tr>
<td>TiO&lt;sub&gt;2&lt;/sub&gt;</td>
<td>% m/m</td>
<td>0.32</td>
<td>0.09</td>
<td>0.93</td>
<td>0.93</td>
<td></td>
</tr>
<tr>
<td>Cu</td>
<td>mg/kg</td>
<td>143</td>
<td>160</td>
<td>509</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Mn</td>
<td>mg/kg</td>
<td>11,000</td>
<td>1,100</td>
<td>1,160</td>
<td>630</td>
<td></td>
</tr>
<tr>
<td>Pb</td>
<td>mg/kg</td>
<td>22.3</td>
<td>100</td>
<td>3,150</td>
<td>54</td>
<td></td>
</tr>
<tr>
<td>Zn</td>
<td>mg/kg</td>
<td>1,040</td>
<td>5,340</td>
<td>3,180</td>
<td>190</td>
<td></td>
</tr>
</tbody>
</table>

1) mixed biomass is a mix of paper sludge, waste wood and green wood
2) boiler type:
   - PFB = pulverized fuel boiler
   - GFB = grate fired boiler
   - FBB = fluidized bed combustion boiler
3) average values of Dutch coal fly ashes

### Forestry

Ashes from combustion of clean wood (including forest residues, bark, cut-offs and saw dust) when not contaminated are basically suitable for recycling to the forests to restore the nutrient balance of the forest and also for soil liming to counteract acidification of the soil (both are closely related). These applications are practiced in e.g. Scandinavian countries and Germany [20; 21]. See further the case Nutrient recycling in forests. The utilisation of wood ashes in forestry is covered by several national fertilizer regulations whereby also some requirements for trace element concentrations are given (see Table 3).

### Agriculture

Due to its content of nutrients, biomass ashes can be used in agriculture. There are three main applications:
- fertilizer; directly or indirectly (as raw material for fertilizer production),
- soil improvement by improving the structure of the soil,
- addition to compost to improve the composting process and the final quality of the compost.

Ashes from clean wood are already used as fertilizer in Germany and Denmark (also straw ash), based on existing fertilizer acts. Ashes from combustion of poultry litter are used as fertilizer in UK.

Regulations for use of secondary materials as fertilizer exist on EU level and national level. If the use of biomass ash is covered in national acts, than it is mostly on wood ash and for the coarse ashes only (bottom ash and/or the first filter step). Table 3 gives a compilation of requirements on biomass ashes for fertilizers in several EU member states. It can be derived that the national regulations for use of biomass ash as fertilizer differs strongly (both limit values and parameters).
### Tab. 1. Survey of (potential) applications for biomass ashes [8 to 23].

<table>
<thead>
<tr>
<th>Sector</th>
<th>Application</th>
<th>Function</th>
<th>Level</th>
<th>Ash types</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forestry</td>
<td>Nutrient recycling</td>
<td>Restoring nutrient balance</td>
<td>IM</td>
<td>Wood ash</td>
</tr>
<tr>
<td>Agriculture</td>
<td>Soil liming</td>
<td>Counteract acidification</td>
<td>IM</td>
<td>Wood ash</td>
</tr>
<tr>
<td>Agriculture</td>
<td>Fertilizer</td>
<td>Ca, P, K, Mg, S fertilizer</td>
<td>IM</td>
<td>Wood ash</td>
</tr>
<tr>
<td>Agriculture</td>
<td>Raw material fertilizer</td>
<td>Ca, P, K, Mg, S fertilizer</td>
<td>IM</td>
<td>Wood ash</td>
</tr>
<tr>
<td>Agriculture</td>
<td>Compost</td>
<td>Improving composting process and quality</td>
<td>IM</td>
<td>Wood ash</td>
</tr>
<tr>
<td>Agriculture</td>
<td>Soil improvement</td>
<td>Improving structure soil</td>
<td>IM</td>
<td>Wood ash</td>
</tr>
<tr>
<td>Civil engineering</td>
<td>Infrastructural works (embankments, fillings)</td>
<td>Filling material</td>
<td>IM</td>
<td>Wood ashes</td>
</tr>
<tr>
<td>Civil engineering</td>
<td>Road Construction material</td>
<td>Binder/filling material</td>
<td>IM</td>
<td>Wood fly ash</td>
</tr>
<tr>
<td>Civil engineering</td>
<td>Asphaltic filler</td>
<td>Raw material</td>
<td>IM</td>
<td>biomass fly ashes</td>
</tr>
<tr>
<td>Civil engineering</td>
<td>Sludge stabilisation</td>
<td>Binder</td>
<td>IM</td>
<td>Wood ash</td>
</tr>
<tr>
<td>Civil engineering</td>
<td>Soil stabilisation</td>
<td>Filler/lime substitution</td>
<td>IM</td>
<td>Biomass fly ash</td>
</tr>
<tr>
<td>Mining</td>
<td>Back-filling</td>
<td>Filler</td>
<td>IM</td>
<td>Waste wood fly ash</td>
</tr>
<tr>
<td>Industry</td>
<td>Phosphor production</td>
<td>Phosphor source</td>
<td>RS</td>
<td>Sewage sludge ash</td>
</tr>
<tr>
<td>Energy</td>
<td>Zeolites</td>
<td>Raw material</td>
<td>LS</td>
<td>Biomass ash</td>
</tr>
<tr>
<td>Energy</td>
<td>Biogas purification</td>
<td>Reagents</td>
<td>PS</td>
<td>Wood ash</td>
</tr>
<tr>
<td>Energy</td>
<td>Synthesis of bio diesel</td>
<td>Catalyst</td>
<td>LS</td>
<td>Wood ash, rice husk ash</td>
</tr>
<tr>
<td>Energy</td>
<td>Flue gas cleaning</td>
<td>desulphurisation sorbent</td>
<td>IM</td>
<td>Paper sludge ash</td>
</tr>
</tbody>
</table>

LS = investigated at lab scale 
PS = investigated at pilot scale 
RS = investigated at real-scale 
IM = implemented

### Tab. 3. Compilation of requirements on biomass ashes for fertilizers and nutrient recycling in several EU member states [mg/kg] [22].

<table>
<thead>
<tr>
<th>Element</th>
<th>CZ</th>
<th>D</th>
<th>NL</th>
<th>Se</th>
<th>DK (new)</th>
<th>FIN</th>
</tr>
</thead>
<tbody>
<tr>
<td>As</td>
<td>mg/kg</td>
<td>10</td>
<td>40</td>
<td>75 to 375</td>
<td>30</td>
<td>25</td>
</tr>
<tr>
<td>B</td>
<td>mg/kg</td>
<td>800</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ba</td>
<td>mg/kg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cd</td>
<td>mg/kg</td>
<td>2</td>
<td>1.5</td>
<td>6.3 to 31.3</td>
<td>30</td>
<td>5 straw</td>
</tr>
<tr>
<td>Cr</td>
<td>mg/kg</td>
<td>100</td>
<td>375 to 1875</td>
<td>100</td>
<td>100</td>
<td>300</td>
</tr>
<tr>
<td>CVI</td>
<td>mg/kg</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cu</td>
<td>mg/kg</td>
<td>100</td>
<td>375 to 1875</td>
<td>400</td>
<td>600</td>
<td>700</td>
</tr>
<tr>
<td>Hg</td>
<td>mg/kg</td>
<td>1,0</td>
<td>1,0</td>
<td>3.8 to 18.8</td>
<td>3</td>
<td>0,8</td>
</tr>
<tr>
<td>Mo</td>
<td>mg/kg</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ni</td>
<td>mg/kg</td>
<td>300</td>
<td>80</td>
<td>150 to 750</td>
<td>70</td>
<td>60</td>
</tr>
<tr>
<td>Pb</td>
<td>mg/kg</td>
<td>100</td>
<td>150</td>
<td>333 to 2,500</td>
<td>300</td>
<td>120 wood ash for forest</td>
</tr>
<tr>
<td>Se</td>
<td>mg/kg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tl</td>
<td>mg/kg</td>
<td>1,0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>mg/kg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zn</td>
<td>mg/kg</td>
<td>1,500 to 7,500</td>
<td>7,000</td>
<td>1,500</td>
<td>4,500</td>
<td></td>
</tr>
<tr>
<td>PFT</td>
<td>mg/kg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dioxins</td>
<td>ng/kg</td>
<td></td>
<td></td>
<td>3.8 to 19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PCB</td>
<td>mg/kg</td>
<td></td>
<td></td>
<td>75 to 375</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PAH</td>
<td>mg/kg</td>
<td>2,300 to 11,500</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 the concentrations shall be calculated to the ‘value determining’ component of the fertilizer/biomass ash like phosphorus, potassium or magnesium. The limit values itself depends also on the ‘value determining’ component.

### Building materials

Coal fly ash is widely used for the production of cement and concrete since decades. Also furnace bottom ash is used in concrete as a fine aggregate, especially in masonry blocks. Depending on properties and especially the chemical and mineralogical composition of the ashes, biomass ash can be used in building materials for production of cement, alternative binders and concrete. The technical suitability and feasibility depends highly on the properties of the ashes. Examples of applications which are at least investigated at real-scale are:

- bottom ash from biomass fired fluidised bed combustion boilers for concrete blocks, especially when quartz sand is used as bed material. The utilisation of coarse and fine biomass ashes as inert aggregate or filler is already covered by the aggregate standards for different applications (e.g. EN 12620 Aggregate for concrete).
- fly ash from paper sludge combustion as binder for non-structural concrete and sand-lime brick production. Important is to steer the combustion temperature to have a sufficient reactive lime.
- fly ash from wood combustion as raw material for clinker production. However, the addition is limited due to the content of undesired components, like alkalis and sulphur.
- fly ash from wood combustion production of sand-lime bricks. Real-scale tests have been performed to use wood ash as partial replacement of lime and fine sand in sand-lime bricks. the addition was limited to less than 5% m/m. The implementation was put on hold due to the high transport costs.

Coal fly ash from co-combustion with biomass is used as reactive (pozzolanic) filler in concrete in several countries. The European technical standard EN 450-1 Fly ash for concrete [24] allows co-combustion up to 50% m/m fuel based for virgin wood only, whereby the ash amount of the co-combustion material does not exceed 30% m/m ash based. The latter is normally no bottle-neck due to the low ash content of wood pellets compared to coal. Co-combustion of other biomass is allowed up to 40% m/m (included mixes with virgin wood), if the biomass is listed in the EN 450 (see Table 4) and all product re-

### Tab. 4. Types of co-combustion materials according to EN 450-1 [24].

| 1 Solid Bio Fuels conforming to EN 14588:2010 including animal husbandry residues and excluding waste wood |
| 2 Animal meal (meat and bone meal) |
| 3 Municipal sewage sludge |
| 4 Paper sludge |
| 5 Petroleum coke |
| 6 Virtually ash free liquid and gaseous fuels |
tic fillers. Implemented applications in civil soil stabilisation and production of asphalt.

Fly ash can be used as a substitute for sand in concrete mixes. It is used as a fine aggregate in concrete to improve its workability and to reduce its water demand. Fly ash is also used in the production of Portland cement as a replacement for clinker.

Civil engineering

Fly ash can be used in road construction for various applications, including:

- **Base course**: Fly ash is used as a component in the base course of roads to improve its durability and load-bearing capacity.
- **Stabilisation**: Fly ash is used in the stabilisation of unbound materials such as gravel and sand.
- **Subbase**: Fly ash is used in the subbase layer of roads to improve its load-bearing capacity.
- **Base**: Fly ash is used in the base layer of roads to improve its load-bearing capacity.
- **Subgrade**: Fly ash is used in the subgrade layer of roads to improve its load-bearing capacity.

Industry

Due to the high availability of fly ash, it is used in various industries, including:

- **Cement Industry**: Fly ash is used as a replacement for clinker in the production of Portland cement.
- **Concrete Industry**: Fly ash is used in the production of concrete to improve its durability and to reduce its water demand.
- **Construction Industry**: Fly ash is used in the production of construction materials such as bricks, blocks, and tiles.
- **Waste Management Industry**: Fly ash is used in the management of waste, including in the production of construction materials and in the treatment of industrial waste.

Mining

Coal fly ash and biomass ashes are used as fillers in mine shafts and subsurface mine workings. They are used to improve the stability of mine shafts and to reduce the risk of collapse.

Industry

Due to the dependency of imports of phosphorus in most European countries, there are several efforts and initiatives to satisfy the future use considering the processing of sewage sludge and also the reuse of ashes. Phosphorus is an essential element for today’s life. It is used in essential applications like fertilizers, steel production and pesticides.

In November 2013, the German Phosphorus Platform was found as a network of stakeholders from science, industry and public bodies to establish sustainable phosphorus management in Germany through a more efficient use of phosphorus as well as effective recycling and reprocessing. Core to the approach of DPP is identifying and implementing innovative technologies that allow economically feasible recycling of phosphorus on a broad scale but also through improved use of phosphorus in already existing manufacturing processes. This includes increases in production efficiency as well as re-using production waste as input material were possible [27].

In October 2017, Germany has released a new sewage act. By this, after an interim period, no sewage sludge from medium and big sewage plants are allowed for fertilisation and phosphorus has to be recycled from the sewage sludge [28].

Also in France it is expected that in 2020 100,000 tons/year of sewage sludge ash will be used to replace phosphate ore for the production of phosphorus [17].

In Japan the option of the application of biomass fly ash for the synthesis of zeolites was reported. Potassium was wet extracted from biomass fly ash and the aqueous solution was used for hydrothermal synthesis of K-zeolites [13]. Zeolites are used for many applications like absorption, in detergents, and for cracking of crude oil.

Energy

The use of biomass ash for energy production is very specific. A few studies have been reported about the use of wood ash and rice husk ash as a catalyst to produce biodiesel from Jatropha oil [16] or palm oil [11] respectively. Another study reported the use of wood ash for the purification of biogas by trapping CO2 and H2S [12]. Fly ash from paper sludge combustion is used as a desulphurisation sorbent in some combustion processes.

Case: Nutrient recycling in forests

In a natural situation most of the biomass (leaves, needles, branches and finally the stem) will fall on the ground near the tree or plant. In this way the nutrients are kept within the ecosystem. The nutrient balance of an ecosystem is influenced by several factors especially by wash-off of compounds and soil erosion (weathering of minerals) whereby nutrients (like K, Ca, Mg and P) become available for organisms and by deposition from the atmosphere [29]. The latter is mainly relevant for nitrogen. Nitrogen can also be bound from the atmosphere by specific plants. Figure 6 gives a simplified illustration of the recycling of nutrients and inputs and outputs of a forest ecosystem.

When biomass is harvested, the ecosystem is not closed anymore as nutrients are taken away together with the biomass. Altterra Wageningen UR assessed the nutrient balance in relation to the nutrient balance for Ca, Mg, K and P [30]. Nitrogen was excluded in this study as no depletion is expected due to the high level of deposition in the Netherlands. A negative nutrient balance is hardly calculated for richer soil types (loamy and clayey soil types), but for poorer soils (sandy) depletion occurs, especially for Ca and K, for all growth classes. For some situations depletion of these elements was calculated even after one har-
vesting. It was remarked by the authors that the calculation shows high uncertainties, especially about the relation between uptake of nutrients in parts of the trees and the availability of nutrients and further the impact of deposition and weathering for phosphorus on the phosphorus balance. Table 6 gives an indication of the removal of macro-nutrients N, P, K and Ca (data about the other macro-nutrients Mg and S were not given) due to extraction of biomass in several forests in the United States [30]. Two types of harvesting were compared, namely conventional harvesting (stem only) and so-called ‘whole tree harvesting’, whereby the complete tree including branches, leaves etc. is removed from the forest. As most nutrients are present in the living parts of the tree, whole tree harvesting leads to considerably higher nutrient loss than conventional harvesting where just the stems are taken away [31-33].

In several countries, like Denmark, Sweden and Finland, spreading wood ash in the forests is practiced to recycle nutrients or as liming agent. In this way macro- and micronutrients are recycled, with exception of nitrogen as this compound is not bound in the fly ash during combustion. However in many regions in the developed countries there is significant contribution to the nutrient balance by atmospheric deposition. Besides the nutrient balance, recycling of ashes in the forests encompasses many aspects to be taken into account, especially:

- biomass fly ashes have a very high pH, which may influence the flora and fauna of the top soil in the forest. Pretreatment by carbonation in open air may reduce this effect.
- content and bio-availability of heavy metals. When the ashes are returned to the same area where the biomass originated from, the heavy metal burden is not influenced on a macro level. However, the bio availability may differ due to different speciation.

Due to the increase of energy production from biomass, more biomass ashes are generated in the EU than recent decades. According to the EU policy, generation of waste has to be avoided. Therefore, utilisation of biomass ashes has to be developed further as a significant part of the biomass ashes are disposed. The re-use of these biomass ashes is also relevant because biomass ashes contain nutrients, which are taken away with the biomass.

A lot of potential applications for biomass ashes have been identified. However, practice is stubborn and only a limited amount is implemented on a large scale. This can be attributed to several aspects as relatively small volumes per source, variations in (chemical) properties, lack of knowledge and the non-maturity of the market (not in all countries).

The logistic chain for biomass ashes is a very important aspect in the development of utilisation due to the relatively small volumes per plant compared to coal ashes. This chain may also include stockpiling and processing before supply to end user.

Processing of biomass ash may help to improve specific properties and to create a more consistent and uniform quality. Examples are:

- carbonation to lower the pH by weathering
- forced leaching to remove heavy metals and/or nutrients
- granulation to get ashes which can be spread in the forests without dust and acts as a slow release fertilizer
- blending, which is performed on a routine base with coal fly ash
- Milling to create a more reactive biomass ash.

Another positive influence to promote the utilisation of biomass ashes is to share the existing knowledge and experience in different countries. Especially regarding the

**Evaluation and conclusions**

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Another positive influence to promote the utilisation of biomass ashes is to share the existing knowledge and experience in different countries. Especially regarding the
use of wood ashes for nutrient recycling and soil liming in the Scandinavian countries.

Main conclusion is that on EU scale, utilisation of biomass ashes is at the beginning of the transformation process from waste into a useful product. The experience with this process for coal fly ash and the experience with biomass ash utilisation in countries like in Scandinavia may be very helpful to accelerate this process in the single countries.

Literature


[26] [DPP : https://www.deutsche-phosphor-plattform.de/english/].


VGB-Standard

Fire and Explosion Protection in Biomass Power Plants

Edition 2013 – VGB-S 50180-00 2013-12 EN

DIN A4, 52 Pages. Price for VGB members* € 80,–, for non members € 120,–, + VAT, shipping and handling

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