Options for increased use of ash from biomass combustion and co-firing

A pile of biomass ash from a grate fired boiler

IEA Bioenergy

IEA Bioenergy:
Task 32: Biomass Combustion and Cofiring

IEA Bioenergy Task 32

Deliverable D7

Options for increased use of ash from biomass combustion and co-firing

Authors:

Frans Lamers (DNVGL), Marcel Cremers (DNVGL), Doris Matschegg (Bioenergy2020+), Christoph Schmidl (Bioenergy2020+), Kirsten Hannam (CFS - Natural Resources Canada), Paul Hazlett (CFS - Natural Resources Canada), Sebnem Madrali (CANMET – Natural Resources Canada), Birgitte Primdal Dam (Emineral A/S), Roberta Roberto (ENEA), Rob Mager (Ontario Power Generation), Kent Davidsson (SP Technical Research Institute of Sweden), Nicolai Bech (StandardConsult ApS), Hans-Joachim Feuerborn (VGB), Angelo Saraber (Vliegasunie),

Published by IEA Bioenergy

Table of Contents

1 Introduction

According to the World Bioenergy Association, energy from biomass contributes 59,2 EJ/yr or 10.3% to the global primary energy supply (World Bioenergy Association, 2017, data 2014). Using biomass, 493 TWh of renewable electricity was generated, comparable with around 2% of worldwide electricity production.

Biomass dominates the renewable fraction in derived heat (heat produced in power plants) and direct heat (directly consumed in end sectors). The renewables share is 7.1% in derived heat and 27.7% in direct heat. In both sectors, the contribution of biomass is more than 95%.
The heat sector is the single most important future development sector for biomass.

The current practice implies that sizeable amounts of ashes from biomass are generated. All of this ash needs to be suitably managed. At an average ash content of 3% in biomass and an average electrical output of 1.5 MWh/ton of biomass, an electric production of 483 TWh means that around 10 Million tons of ashes are globally produced from electricity production. For heat-only production additional quantities of ash are generated.

This report attempts to provide an overview on present practices in ash management from biomass (co)combustion, based on country reports for experiences in 6 countries, namely Austria, Canada, Germany, Italy, the Netherlands and Sweden. Other members in IEA bioenergy task 32 that contributed were South Africa, Denmark and the United Kingdom. The report consists of a short overview section, giving the main highlights and conclusions that can be extracted from the country reports. This overview also provides a separate table with the utilization practices. The country reports for Austria, Canada, Italy, the Netherlands and Sweden are added as separate appendices to this report.

Additional to the country reports a recent Dutch report on the use of wood combustion ashes in soil amendment and fertilizing was used as a reference (NMI, 2018)

On a worldwide level, no or a limited number of guidelines with best practices have been developed in the field of ash management. To strengthen utilization possibilities on a supranational scale, improved knowledge exchange and sharing are required. This report shows the extent of existing practices and differences in application. On some aspects harmonization efforts may be required (such as the use in forests) but generally this report is meant to form a starting point for improved knowledge sharing.

2 Summary of country practices

2.1 Ash quantities and sources

In Table 2.1 and Table 2.2, overviews are given on the quantities of ashes and the types of biomass they were generated from. Table 2.1 already shows that there are significant differences between countries, making a generalisation difficult. As an indication:

- In the Austrian codes no distinction is made between wood ash and straw ash. The bulk of ashes is generally referred to as wood ash, straw ash. It seems all wood ash, but if there is a sizable amount of straw ashes, this has strong effects on chlorine content
- Canada – with a high density of forests, shows a high percentage of forest biomass and furthermore residues from paper and pulp mills that are combusted
- Italy only shows wood combustion ashes (quantities relatively 30% higher compared to other countries due to inclusion of residential wood combustion
- In the Netherlands on the other hand, forest biomass (pellets) was typically utilised in co-combustion with coal in percentages of 5 – 15% on calorific content (separately mentioned), stand-alone plants combust waste wood, but there is also combustion of several biogenic sludge fractions that are typically landfilled in other countries;
- Sweden, like Canada has a high quantity of paper and pulp mill residues and forest wood combustion but also uses a lot of waste wood streams in combined heat and power plants. In the country report also ashes from municipal solid waste incineration were included; this was excluded from the quantities in table 1.

Table 2.1 Overview of total ash quantities produced in the countries examined

	Quantities [kton]	Remarks
Austria	133	Only reported ash quantities from industry. Ash quantities from households and ashes being spread on land are not reported
Canada	> 1000	Minimum quantities: Fragmented information based on total pulp and paper mills Canada and wood / forest biomass ashes from Alberta, British Columbia and Quebec
Denmark	91	Figures 2016; 61 kton of straw combustion ashes, 31 k of wood combustion ashes
Germany	400 / 650 (1000)	Figure reported from energy production (at 2% ash) for clean wood and (at 10% ash) for waste wood; in case household combustion is added, quantities for clean wood will exceed 1000 kton.
Italy	855	Consists only of ashes from wood combustion, both from power plants and district heating plants but also around 30% of ashes from small scale residential wood combustion
The Netherlands	234 + 490	234 kton involves specific biomass combustion but including sewage and dung combustion ashes that are not readily incinerated in other countries; 490 kton ashes from co-combustion (5 – 15% of clean wood based on calorific content) in coal fired power plants
Sweden	528 + 114	528 kton involves pure biomass combustion; 114 kton is based on multifuel waste – peat- coal - biomass

Table 2.2 Overview of types of biomass ashes

Biomass type	Forestry wood	Demolition wood	Straw	Grown biomass	Sewage sludge	Paper sludge	Manure	Liquid Biomass
Austria	X			X				
Canada	X	X				X		
Denmark	X	X	X					
Germany	X	X		X	X	X	X	X
Italy	X	X						
The Netherlands	X	X			X	X	X	
Sweden	X	X				X		X

In focus	Out of focus

Table 2.2 shows the beforementioned differences in biomass combustion fuel sources, also indicating that the qualities of biomass ashes per country can differ significantly. Austria as an example where straw and grown biomass are combusted in higher percentages, whereas Netherlands is an example for incineration of sewage sludge and several types of manure. These differences in biomass types have of course an impact on the possibilities for utilization. In principle it is proposed not to focus on the biomass types that are out of focus

2.2 Types of Utilization for the ashes per country

For the management of the ashes, several classes of utilization can be distinguished. They are different per country.

Since the types of biomass fuel inputs are not always strictly regulated, also the final ash products show large variations in quality, making it challenging to meet utilization standards. In 3 out of 5 of the country reports, landfill and disposal is therefore mentioned as the foremost final destination.

In all other types of utilization there are limitations because of technical or environmental requirements, either from European or Country by country standards, or from project specifications in which the biomass is used.

Table 3 provides an overview of the utilization of ashes from biomass combustion in the different countries. In the paragraphs after table 3, remarks are made per type of utilization

Table 2.3 Utilization of biomass ashes in Austria, Canada, Italy, the Netherlands and Sweden

Country Utilization	Austria	Canada	Denmark	Germany	Italy	Netherlands	Sweden
Landfill/disposal	**Yes, A**	**Yes, A**	Yes, A	Yes, A	Yes, A	Yes, a	**Yes, A**
Cement raw meal addition	Yes, B	Yes, b			Yes, B		No
Cement and concrete filler					Maybe, B	Yes, B	
Use in forestry	No		**Yes, A**			Maybe, B/C	Yes A
Soil amendment / fertilizer	Yes, C	Yes, A	**Yes, A/C**	Yes, A	Yes, A	**Yes, C**	No
Addition to Compost	Yes				Maybe	Maybe, B/C	
Asphaltic filler	Maybe, B	No			Yes, B	Yes, B	No
Underground mining				Yes, A	No	Yes, A	No
Civil engineering	Yes, a	Yes, B		Yes, A	Maybe, B/C	Yes, B/C	Yes, B/C
Other building materials[a]	Yes , B/C				Maybe, B/C	Yes, B/C	No
Other uses undefined		Yes, B/C					
Export, undefined					**Yes, A/C**		Yes, A/C
unknown	Yes					Yes	Yes

Yes = Is applied in a country
Bold = Major application in a country
Maybe = application in review / research
A = Final use
B = Depending on technical specifications
C = Depending on regulatory requirements

2.3 Remarks per type of end use

2.3.1 Landfill

Conforming to Waste Hierarchy as defined in the Waste Framework Directive (Directive 2008/98/EC on waste), the *minimum standard for removal* of waste is disposal. This means that that there is no ban on disposal on a landfill for biomass ashes. Four out of five of the country reports are within the EC region. Within four of five countries landfilling is the preferred solution.

2.3.2 Use in forestry

Not all countries have regulations for the use of biomass ash or wood ash in forestry. In case there are no regulations, the use in forestry has to be qualified as *Dispersion of waste*, which is forbidden. This counts for Austria, Italy and the Netherlands although studies have been performed into soil amendment.
Sweden as an example does have specific regulations and policy to return ashes from forestry origin back to the forest if it is not contaminated. The policy to return ashes to the forest is considered a mitigation strategy against acidification.
In Canada regulations for the use in forests are different on a Province by province level.
Both in Sweden and Canada regulations focus on technical quality (Content of lime / nutrients) and on environmental quality (trace elements).

A major drawback on the use of biomass ashes in forests is their solubility and reactivity that may have a negative effect on vegetation and soil life. To reduce instantaneous release of soluble components from ashes, they can be pelletized with binders so that nutrients will be released more slowly. This is also done in Sweden (NMI, 2018).

2.3.3 Fertiliser use / soil amendment

The use of biomass ashes for fertiliser use in agriculture is regulated by the addition of the specific nutrient (CaO, K_2O or SO_3 – or phosphate if manure or sewage sludge is combusted) and the trace element composition. The trace element limits in practice often prevent the use of biomass ashes in such application.

Presently the EU Decree 2003-2003 regarding fertilisers is being revised. Additional to a defined list of fertiliser products, also product function categories will be defined that will allow “alternative” fertilisers to be reviewed according to their major component composition and trace element / heavy metal contents. Basically 4 types of Categories will be distinguished for ashes, based on their contents of fertilizing elements, the types being C ashes (rich in lime), K ashes (rich in K, P, S), CK ashes (intermediate group) and S ashes (rich is SiO2, depleted in fertilizing components). S ashes are not suitable for fertiliser use. Basically all bottom ashes and 30% of fly ashes are S Ashes and not suitable for fertiliser use.
The expectation is that in a lot of cases, contents in Pb and Cd will prevent the use as a fertiliser component (NMI 2018).

2.3.4 Addition to compost

In some countries (such as Austria) a maximum of 2% of biomass ashes can be added within the composting process to improve the process. Also Germany allows the use of ashes in compost, even up to 5%. This is done to improve the pH of the compost and improve the lime content of the compost for fertilizing. Within the EU Decree on fertilizing materials (previously mentioned) CMC additions to compost are allowed, up to 5%. Any additives must have a proven effect on composting process or lowering of environmental impact. This has to be substantiated and demonstrated. Any additive has to be REACH registered in Europe.

2.3.5 Cement raw meal constituent

In principle, several types of biomass ashes (preferably clean wood but also for instance paper sludge ashes) can be used as raw meal substitute for the production of Portland clinker, which is the basis for most type of cements. In that case the biomass ashes are alternative raw material carriers for CaO, SiOs, Al2O3 and Fe2O2. The requirements for this application are established in bilateral contracts. This type of utilization necessitates a nearby cement factory that needs specific additions to their limestone raw materials and in view of the scale of cement production a sizeable feedstock. The cement industry is a mature market with stakeholders that know the possibilities of use of alternative streams for their product and that are proactive in finding raw meal constituents.

2.3.6 Cement and concrete fillers

Coal fly ash from co-combustion is used in concrete, both structural and non-structural. According to the European standard for fly ash in concrete (EN 450), it is allowed to co-fire green wood up to 50% m/m fuel based if no other fuels are co-fired. If other fuels are co-fired the maximum co-combustion percentage is 40% m/m fuel based and 30% m/m ash based. There is also a limitative list of fuels which may be co-fired. Ashes from more than 50% co-combustion cannot be utilized as a filler for Portland cement according to EN 450. There is the possibility however to demonstrate conformity with coal fly ashes.

The application of biomass ash in blended cements is not regulated. The European standard for cement (EN 197-1) does not allow this type of ash to be used as compound.

2.3.7 Asphalt concrete filler

Depending on the grain size distribution of aggregates for asphalt concrete, fillers need to be added to asphalt concrete mixtures to improve the grain size distribution related properties. These fillers can be prepared from limestone but also different types of fly ashes. In the Netherlands common biomass ash types used in asphalt concrete fillers are sewage sludge ash and biomass fly ash. Technical product regulations allow this. In other countries (such as Austria) studies and tests are performed to evaluate possibilities to introduce this use.

2.3.8 Underground mining`/ international use

Underground mining cavities – often in surrounding countries need a lot of material for structural filling. Biomass ashes, in particular the contaminated ashes with lower economic values (or even higher negative economic value) can be used for that application.

2.3.9 Civil engineering

Specifically bottom ashes from bio energy plants using waste wood can be used as a road construction base material (embankment material, road foundation material etc.), in some countries in combination with solid waste incineration ashes

2.3.10 Other building materials

At specification of the building materials producer, biomass ashes can be used as a raw material / intermediate product for industrial construction materials, cement replacement in building products and desulphurization sorbents.

3 Improving the use of ash

Categorize ashes

There is a large variety of biomass types available on the market and a variety of boilers in which they are converted into heat and / or power. In principle, the utilization should be categorized per type of biomass and per type of boiler. In the framework of this review, we propose to distinguish the following main types of biomass ashes:

- Ashes from clean forest wood combustion (including grown wood)
- Ashes from combustion of used or contaminated wood
- Ashes from combustion of straw
- Ashes from grown biomass

This means that solid waste combustion ashes, sewage sludge ashes, paper ashes and animal manure ashes should be excluded from biomass ash reviews.

Further we propose to distinguish fine ashes and coarse ashes in each of these groups.

Discourage landfilling of ashes

The country reports show that landfill of ashes is the main outlet in many countries. In view of low cost of landfill compared to developing new utilizations this is not unexpected. Also the heavy metal content of ashes will in some cases prevent specific types of utilization. However in bound products the heavy metal content in the ashes should not burden the environment. Use of incentives to discourage landfilling may favour development of competitive types of utilization. A better convergence of the nationally defined regulations on environmental limits for applications may support development of successful utilizations.

Communication of successful applications and sharing experiences / guidelines with best practices

The country reports show that in most individual countries a country-specific focus of utilization of the ashes is chosen. Successful utilizations in the construction sector are often not copied. We recommend that guidelines with best practices be developed to make sure that successes and experiences in one country can be easier implemented in another country based on sharing of experiences (fields of utilization to be considered for instance forestry use, use as a fertilizer, use in composting, asphalt fillers, use in bricks and in sand-lime bricks, soil stabilisation recipes)

Aligning circularity targets with environmental regulations

In practice, European and world wide recommendations to increase circularity are not leading in reviewing utilisation possibilities of recycled products in individual countries. A guideline (for instance by the European Commission) on how to value recycling of products that may contain an enrichment in microelements, as opposed to landfilling them, may lead to streamlining of environmental regulations that are unnecessary restrictive on utilization.

Waste Regulations

In a number of countries regulations do not allow recycling of wood ashes in the forests as it is seen as dispersion of waste; within the definition of use in forest, within that application the material is not seen as a fertiliser and therefore does not fall under the classification of biomass ashes under the fertiliser regulations. An allowance to use biomass ashes as soil amendment in forests and an end of waste classification of biomass ashes for this purpose would remove one of the bottlenecks for ash recycling.

Transport regulations

The current EU regulation on waste shipment (EU regulation) does not specifically include ashes from biomass combustion on the a green list (or even orange list) material. In this way, biomass ashes are automatically classified as a red list material, the most stringent category regarding possibilities to transport. This does not fit with the nature of the material. A classification on the green list would make cross-border transport for utilization less complicated.

Use of ashes in forestry

A clearer positioning of the use of ashes in forests (nutrient recycling) is recommended. Development of a Guideline with Best Practices and regulatory considerations in for instance Sweden, may help to facilitate introduction of this kind of application in other countries.

Fertiliser and compost regulations

The requirements for fertiliser and compost regulations often cannot be met by biomass ashes due to the stringent requirements and the calculation method. A modification of the requirements and the calculation method would be helpful to provide an entry to soil amendment/fertiliser market. The European Fertilisers Regulation (EC 2003/2003) exists but a revision is in development, opening possibilities to use ashes in fertiliser components and in compost all over Europe. Expected environmental demands within the EC Fertiliser Regulation still are restrictive on utilization of ashes in this field.

4 Country report Austria

Authors: Doris Matschegg (Bioenergy2020+), Christoph Schmidl (Bioenergy2020+)

4.1 Ash sources

4.1.1 Current status of biomass combustion

The Austrian total primary energy supply amounted to 1,373PJ in 2015. The share of renewable energies was 32.8%. Fossil fuels (petroleum, natural gas, coal) continue to dominate even if the share or renewable energy was significantly increased in the last decades. In Austria bioenergy is the most important source of renewable energy contributing almost 60%. Hydropower is the second main pillar of renewable energy supply in Austria with a share of approximately 30-35% (varying from year to year). In recent years the highest relative growth has been observed for photovoltaics, ambient heat (heat pumps) and wind while the highest absolute growth is still seen for bioenergy. Figure 4.1 gives an overview of the development of the Austrian energy supply since 1971.

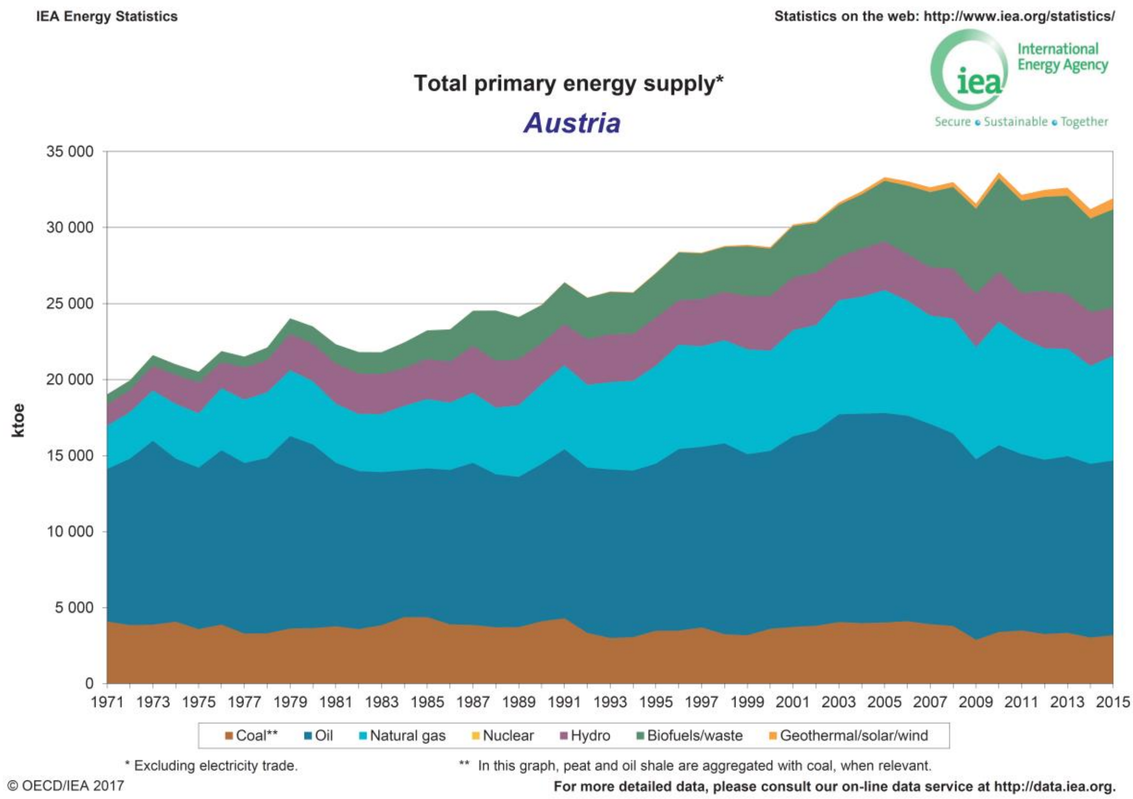


Figure 4.1 Austrian energy supply 1971 - 2015

The most important bioenergy carriers in Austria are Wood Chips / Sawmill by-products / bark with almost 34% of total bioenergy in 2015 and firewood with 24%. Other important shares are coming from waste liquor from paper industry and biofuels (both around 12%). Wood pellets are mainly used in small-scale systems in Austria and contributed 5.4% to total bioenergy in 2015. Table 4.1 gives an overview of the Austrian renewable energy consumption by technology for 2014 and 2015. Figure 4.2 shows the solid biofuel consumption in Austria between 2007 and 2016. The decrease in 2014 and 2015 was mainly caused by mild winter temperatures and the resulting lower number of heating degree days.

Table 4.1: Austrian renewable final energy consumption by technology

	Total (GWh)	Total (GWh)	Change	Share
	2014	2015	204-2015	2015
Biogas	1,180	1,159	-1.7%	1.1%
Biofuels	6,722	7,760	+15.4%	7.3%
Renewable district heat[1]	10,116	10.494	+3.7%	9.8%
Geothermal energy	75	84	+12.2%	0.1%
Woodfuel[2]	29,093	31,124	+7.0%	29.2%
Black liquor	7,140	6,532	8.5%	6.1%
Photovoltaics	785	937	+19.3%	0.9%
Solar heat	2,100	2,129	+1.4%	2.0%
Ambient heat	1,976	2,043	+3.3%	1.9%
Hydropower	40,128	39,752	-0.9%	37.3%
Wind power	3,808	4,679	+22.9%	4.4%
Sum	103,124	106,694	+3.5%	100.0%

[1]Renewable share, includes wood waste, wood based fuels, biogas, biogenic liquids, black liquors, other solid biogenics and geothermal energy

[2]Firewood, wood chips, wood pellets, wood briquettes, waste wood, charcoal and biogenic waste

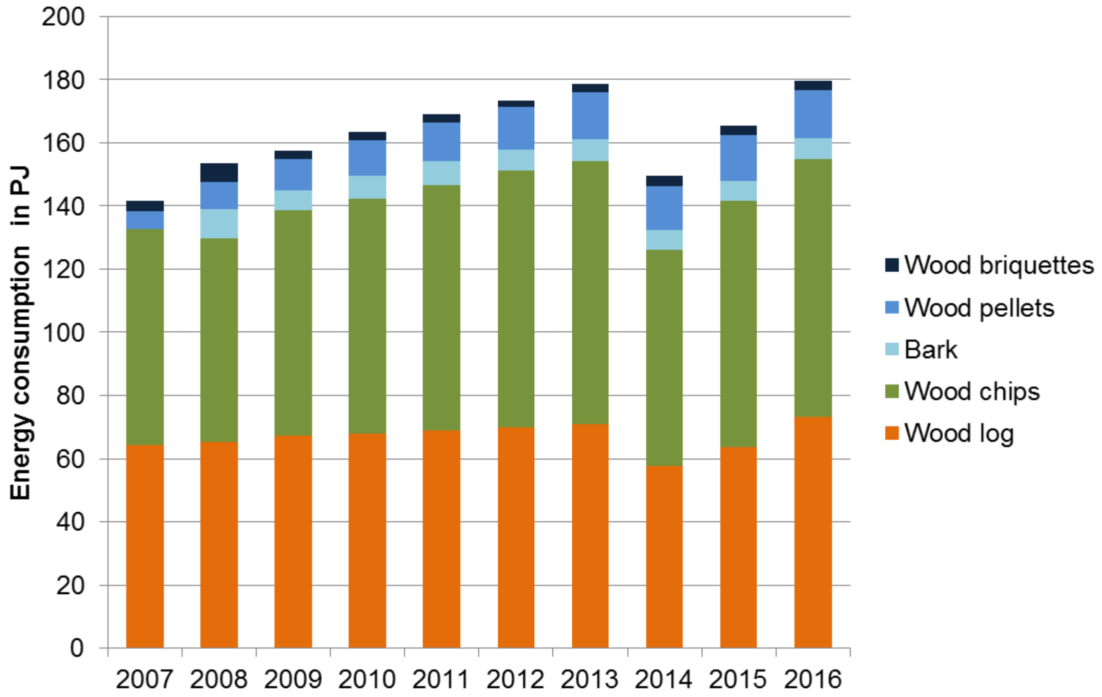


Figure 4.2: Solid biofuel consumption in Austria (2017 - 2016)

Electricity production from biomass

In 2016 111 biomass CHP systems with a nominal electrical capacity of 313MW produced 2128 GWh electricity and 4457 GWh heat. These numbers do not include biogas plants (n=300) and biomass gasification plants (n=22).

Heat production from biomass

More than 2100 biomass fuelled heating plants were in operation in Austria in 2016 and produced 4650 GWh of heat. Main fuels for these plants are wood chips and wood pellets.

Figure 4.3 shows the distribution of CHP and heating plants over Austria.

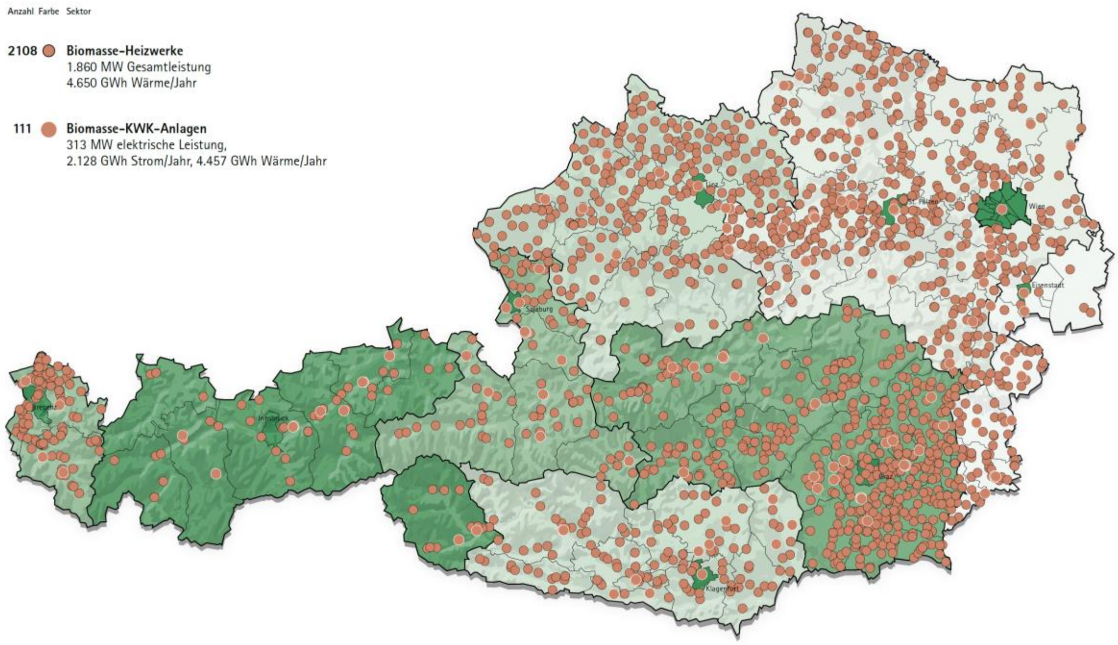


Figure 4.3: Biomass-fuelled CHP and heating plants in Austria

<u>Small-scale combustion of biomass</u>

Biomass-based direct and central heating systems are very common in Austrian households. In 2015/2016 around 54PJ of heat where provided by biomass fuels. As shown in Figure 4.4 biomass combustion thereby is the most important source of residential heat. Together with the biogenic share of district heating (~11PJ) biomass covers almost 40% of the residential heat demand in Austria.

Different to medium and large scale combustion plants, biomass ashes from household combustion appliances are usually not disposed of separately, but mixed with household waste or with the households own compost. In these cases the biomass ashes do not appear as part of the reported data later in this report.

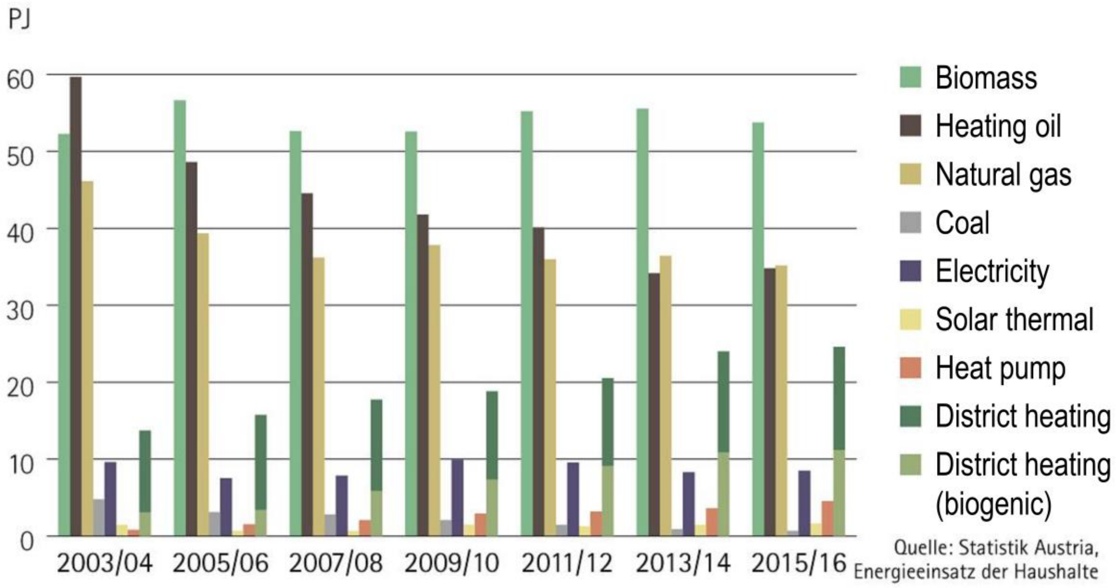


Figure 4.4: Energy sources for space heating in Austrian households

4.1.2 Relation to ash production and quality

In official data 133,461t of biomass ashes were reported as shown in Table 4.2. However, it is assumed that this amount does not reflect the entire volume. For example, biomass ashes from furnaces in households are not included. Furthermore unknown amounts of biomass ashes are spread on to land, without being reported. In these cases the biomass ashes do not appear as part of the reported data.

The Austrian Federal Environmental Agency has therefore estimated the total volume of biomass ashes in its recent report: Biomass ash streams in Austria. Based on reported ash amounts and estimations of non-reported fractions it can be assumed that the total amount of biomass ashes in Austria was about 200,000t in 2013.

Table 4.2: Reported amounts of biomass ashes in Austria (2013)

Ash	Amount 2013 [t]
Wood ash, straw ash	85,388
Wood ash, straw ash (grate ashes)	32,213
Wood ash, straw ash (fly ashes)	4,254
Wood ash, straw ash (micro-sized fly ashes)	3,100
Wood ash, straw ash (dangerous pollutant)	2,243
Plant ash	5,116
Plant ash (grate ashes)	1,147
Total	**133,461**

In the same report the biomass ashes were categorized by combustion technology. As shown in Table 4.3 the size fractionation (mass ratios) between grate, fly and micro-sized fly ash are strongly dependent on combustion technology / plant operation and fuel properties (grain size, density).

Table 4.3: Ash types and mass ratios for different combustion technologies

Technology	Fuel	Grate Ash [%DM]	Fly ash [%DM]	Micro-sized fly ash [%DM]
Grate firing, underfeed furnace	Bark	65-85	10-25	2-10
	Wood chips	60-90	10-30	2-10
	Straw	80-90	2-5	5-10
Grate firing	Wood chips	16	81	3
Circulating fluidized bed	Bark, sludge	5	9	86
	Wood chips, bark	70	-	30

DM…dry mass

4.2 Applications for ash

Several initiatives and research projects have recently addressed the application of biomass ash. The report on biomass ash streams in Austria mentioned above also provides an overview of the current utilization of ashes from biomass combustion in Austria (see Table 4.4). At present, the application/disposal of 126,053t can be attributed, while the use of 7,408t is unknown. Almost half of the biomass ash in Austria is deposited, approximately one third is used for the cement and concrete industry and approximately 11% are used for building materials. All other types of usage play a minor role, with shares in the single-digit range.

Table 4.4: Utilization of biomass ashes in Austria

Utilization	Amount [t]	Fraction [% m/m]	Remark
Landfill/disposal	58,293	43.68	
Composting	5,117	3.83	
CP	2,460	1.84	
Sorting preparation	373	0.28	Additional 29t were treated and passed to CP
Backfilling	5,722	4.29	
Cement and concrete	39,398	29.52	
Building material	14,411	10.80	Additional 5,722t are treated and passed to Backfilling
Soilification	279	0.21	
Unknown	7,408	5.55	
Total	**133,461**	**100**	

4.2.1 Cement and concrete

In Austria, the use of coal fly ash as an additive to raw meal or as a raw meal substitute is practiced in cement plants. According to Swiss BUWAL (2005) the term "raw meal substitute" covers both, the actual substitution of a part of the normal raw material and the use as a raw meal correction additive for an adaption of the elemental composition of the raw meal.

Cement plants which take over biomass ash as a substitute raw material understand the ash as major alternative raw material carrier for CaO, SiO_2, Al_2O_3 and Fe_2O_3. All companies use a quality assurance system for alternative raw materials, which contains technical criteria and environmental criteria.

The use of "various ashes" as raw meal replacement amounted to 123,590t in 2013. The use of "fly ash", in the same year, amounted to 121,666t. The related cement and clinker masses for 2013 amount to 4.39 million tons of cement and 3.16 million tons of clinker. However these figures include also ashes from coal fired plants. A distinction between coal and biomass ash was not done.

In all four biomass ash-using cement plants in Austria, the biomass ash is used exclusively as raw meal substitute for clinker production not as grinding/blending material. A number of standards have to be fulfilled for the use as grinding/blending material; these exclude the use of biomass ash.

4.2.2 Composting

Scepticism or a negative attitude towards the utilization of biomass ash in composting plants is widespread. The reasons for concerns are usually the increased dust formation and the danger of a quality reduction of the compost.

Only a few plants use ashes in relevant quantities. In one of these plants, the limit of the Austrian composting regulations (maximum 2% ash addition) is almost reached.

4.2.3 Agricultural utilization without upstream composting

In Austria, a directive for the utilization of biomass ash in agriculture is in force, which was developed by the Council for soil - fertility and protection in 2013. This includes the legal requirements for the utilization of biomass ash as fertiliser in Austria, limit values for the pollutant content and a quality assurance program.

In general the agricultural utilization has not grown significantly in recent years.

4.3 Improving the use of ash

Compost regulation

The Austrian composting regulation allows a maximum of 2% ash addition in the composting plant. Several plants and institutions propose to increase the permissible amount of ashes to 5%, 8%, 10% or even 15%. The addition of up to 15% ash has no negative impact on the composting process itself. However, the highest (A+) compost quality cannot always be achieved with higher ash contents. Above all the cadmium content of the ash appears to pose a problem.

In the light of the concerns about the use of biomass ash expressed by composting plant operators (see 4.2.2) it appears questionable if a change in the legal limit values will significantly increase the use of biomass ash in this sector.

Innovations

Several recently finished or on-going projects are dealing with utilization pathways for biomass ashes. Following topics are addressed:

- Desulphurisation of biogas by use of biomass ash
    - Reduction of H_2S was successful
    - pH value of biomass ash was decreased significantly → less problems in composting and agriculture
- Use of biomass ash as fertiliser in SRF
- Use of biomass ash as stabilizer in road construction (e.g. forest roads)
- Technical methods for using biomass ash as fertiliser in forestry (how to spread ash into forests)
- Influence of higher shares of biomass ash on composting process
- Economic evaluation of different utilization pathways compared to landfill
- A screening/grading plant for ashes was installed in the province of Salzburg. This allows the subsequent agricultural utilization with a spreader.
- One of the three bitumen-product plants in Austria has already carried out experiments with processed ash fractions in the laboratory. These tests and the utilization of ash fractions abroad in the production of bitumen products (bitumen roofing sheets, bitumen shingles, road asphalt) show that the utilization of processed ash fractions is technically possible.

5 Canada

Authors: Kirsten Hannam (CFS - Natural Resources Canada), Caroline Emilson (CFS – Natural Resources Canada), Paul Hazlett (CFS - Natural Resources Canada), Sebnem Madrali (CANMET – Natural Resources Canada), Rob Mager (Ontario Power Generation)

5.1 Ash sources

5.1.1 Current status of biomass combustion

Canada has a diverse energy portfolio because of its abundant fossil fuel and uranium reserves and extensive river systems. The contribution of renewables to the country's total primary energy production has been increasing steadily to 20% in 2015 [20]. Large hydro accounts for the bulk of Canada's renewable energy capacity (72%), followed by biomass (15%) [20]. Most of Canada's renewable energy capacity is used to generate electricity; in 2015, the contribution of biomass to electricity generation was equivalent to 13 107 GWh [39].

The Canadian forest industry has a long history of combusting spent pulping liquor and wood processing residues to produce heat and electricity for on-site use at pulp and paper mills and sawmills. This industry remains the most important producer of bioenergy in Canada [8,20]. The desire to reduce greenhouse gas (GHG) emissions, displace the use of heating oil in northern communities, and create local employment opportunities has stimulated an expansion of forest biomass-based energy capacity for commercial and institutional heating in the Northwest Territories, British Columbia, Québec and Prince Edward Island [8,12,36]. Recent policy announcements banning traditional coal-fired electricity generation by 2030 [18] are expected to stimulate the growth of bioenergy production on a larger-scale.

In the near-term, coal-burning facilities in Canada can be replaced by or converted to either biomass or natural gas. Natural gas is seen as a convenient "bridge fuel" when phasing out coal because it is widely available in North America at relatively low cost. However, biomass is an appropriate alternative in regions without easy access to natural gas. When the price premium between natural gas and biomass is small, biomass may be more desirable because of the incremental GHG benefits over natural gas.

Ontario Power Generation (OPG) is a government-owned utility company operating in the province of Ontario [50]. In 2003, the Ontario government committed to ceasing all coal-fired power generation by 2014, thereby reducing the greenhouse gas emissions associated with electricity generation from 43 to 6 Mt CO_2 equivalent [39]. To achieve this goal, three coal-fired power plants were permanently closed, and the Atikokan and Thunder Bay plants were converted to biomass. The Atikokan Generating Station (GS) was a 205 MW PC (pulverized coal) single-unit plant which now uses ~ 90 000 Mg of wood pellets yr^{-1}. The Thunder Bay GS was a 150 MW PC single unit plant which now uses ~7 500 Mg of advanced biomass fuel yr^{-1}. Although these facilities are currently operating at low capacity, they will be ramped up to meet increasing demand as required. Thus, OPG has a unique perspective on the process of converting from coal-fired to bio-energy production in Canada. Insight from OPG will be provided throughout this document.

Despite the elimination of coal-fired electricity production in Ontario, coal remains an important energy source in the provinces of Alberta, Saskatchewan, New Brunswick and Nova Scotia. In 2015, Alberta and Saskatchewan alone accounted for 88% of all coal-generated electricity in the country (~58 TWh [40]). Attempts in each province to eliminate or mitigate the greenhouse gas emissions associated with coal burning reflect regional differences in resource availability; conversion to biomass is not always considered the most viable option.

5.1.2 Relation to ash production and quality

National statistics on ash production in Canada have not been compiled. However, a recently completed survey of Canadian pulp and paper mills provides some relevant data [14]. Useful data have also been collected for the provinces of Alberta, British Columbia and Québec (Table 5.1).

Table 5.1 Available data on ash production in Canada

Jurisdiction	Year	Annual production	Reference
Canada - pulp & paper mills only	2013	420 000 Mg (dry weight)*	Elliott & Mahmood 2015 [14]
Alberta – wood ash	2015	59 639 Mg (dry weight)	G. Dinwoodie, 2016 [17]
British Columbia – forest biomass ash	2014	235 449 Mg (dry weight)	Nishio 2016 [42]
		235 449 Mg, broken down by feedstock type: - 71 308 Mg ash contaminated with salt - 63 292 Mg ash contaminated with tires and/or demolition waste - 100 849 Mg un-contaminated ash *235 449 Mg, broken down by ash type*: - 94 652 Mg fly ash - 42 958 Mg bottom ash - 97 838 Mg (mixed or otherwise unidentified ash)	
Québec – wood ash	2007	300 000 Mg (wet weight)	Hébert and Breton 2008 [26]

* 420 000 Mg is an estimate of the total annual ash production rate in Canada; this rate was calculated using ash production rates reported by survey respondents.

National statistics on wood ash quality have also not been compiled. To help fill this gap, data on the chemistry of Canadian wood ash samples is being solicited through AshNet. AshNet is a network of scientists, foresters, industry and government (federal and provincial) representatives who are working to encourage the use of wood ash as a forest soil amendment in Canada. The wood ash chemistry database is publically available on the AshNet website (http://www.nrcan.gc.ca/forests/research-centres/glfc/ashnet/20288) and will be continuously updated. Table 5.2 and Table 5.3 have been compiled from the existing database, which includes ash generated at several Canadian paper and pulp mills and bioenergy facilities (e.g., the Atikokan Generating Station), from a variety of feedstocks (e.g., wood pellets; bark, wood shavings and sawdust; harvesting debris, construction and demolition debris, de-watered pulp mill sludge).

Table 5.2 pH and concentrations of total C and nutrients in fly and bottom ashes collected from bioenergy plants across Canada. Data represent the mean and range (in brackets) for 8 to 9 samples of fly ash and 13 to 16 samples of bottom ash produced from a range of feedstocks and boiler types.

	Fly ash	Bottom ash
pH in H_2O	11.3 (8.6 – 13.8)	10.9 (7.5 – 12.9)
Total C (%)	18.1 (2.7 – 43.0)	20.4 (0.5 – 51.8)
Total N (%)	0.17 (0.04 – 0.4)	0.09 (< 0.01 – 0.3)
Total P (g kg^{-1})	6.3 (3.2 – 10.6)	4.9 (0.1 – 11.9)
Total Ca (g kg^{-1})	153.5 (92.1 – 247.9)	103.7 (3.9 – 211.0)
Total Mg (g kg^{-1})	14.6 (6.4 – 29.4)	11.8 (0.6 – 33.1)
Total K (g kg^{-1})	33.1 (13.5 – 90.8)	24.1 (0.8 – 50.8)
Total S (g kg^{-1})	11.0 (<0.1 – 47.4)	3.8 (<0.1 – 25.9)

Table 5.3 Concentrations of trace elements in fly and bottom ashes collected from bioenergy plants across Canada. Data represent the mean and range (in brackets) for 7 to 9 samples of fly ash and 12 to 16 samples of bottom ash produced from a range of feedstocks and boiler types

	Fly ash	**Bottom ash**
Arsenic (mg kg^{-1})	13.5 (3.6 – 27.9)	20.9 (0.04 – 139.0)
Cadmium (mg kg^{-1})	8.9 (2.3 – 17.8)	2.8 (0.1 – 8.3)
Chromium (mg kg^{-1})	35.2 (15.0 – 67.9)	41.8 (7.8 – 182.0)
Cobalt (mg kg^{-1})	11.5 (4.8 – 20.1)	9.2 (0.1 – 15.6)
Copper (mg kg^{-1})	83.5 (35.0 – 144.6)	62.0 (0.05 – 205.0)
Lead (mg kg^{-1})	20.3 (3.3 – 61.3)	55.7 (0.5 – 369.0)
Molybdenum (mg kg^{-1})	7.9 (2.9 – 36.9)	3.1 (0.2 – 6.2)
Nickel (mg kg^{-1})	41.5 (10.4 – 184.4)	24.0 (3.3 – 47.0)
Selenium (mg kg^{-1})	9.6 (1.5 – 20.0)	6.0 (0.02 – 24.2)
Zinc (mg kg^{-1})	1178.9 (388.9 – 2661.5)	439.2 (32.1 – 1504.0)

5.2 Applications for ash

National statistics on ash utilization have not been compiled for Canada. Again, however, a recently completed survey of Canadian pulp and paper mills provides some useful data on ash management [14]. To date, landfilling remains the most common fate of wood ash produced in Canada.

Table 5.4 Management and disposal of boiler ashes generated at Canadian pulp and paper mills in 2013 [14]

Utilization	**Quantity (Mg)**	**Proportion of the 296 200 Mg of ash produced by survey respondents at Canadian pulp & paper mills (%)**
Landfill	183 100	62
Soil amendment (direct application or in compost)	54 700	18
Other beneficial use	52 500	18

5.2.1 Landfill

Wood ash is often treated as a waste material in Canada and landfilled. However, this situation appears to be changing: in 1995, 84% of the ash produced in power and recovery boilers at Canadian pulp and paper mills was landfilled but by 2013, only about 63% of this ash was landfilled [13,14]. That being said, ash is managed very differently from province to province. Approximately half of the ash produced each year in Alberta and Québec is landfilled (~30 000 Mg (dry weight) in Alberta in 2015 [17]; ~150 000 Mg (wet weight) in Québec in 2007 [26]). By contrast, almost all of the ash produced each year in British Columbia is landfilled (~226 000 Mg (dry weight) [42]).

Perspective from the ground: Ontario Power Generation

The mass of biomass ash produced at the Atikokan and Thunder Bay Generating Stations represents <1% of the mass of pellets combusted (i.e., <975 Mg ash $year^{-1}$). This ash is currently disposed of at a municipal landfill. Given the relatively small volume of ash produced each year, there is currently no significant economic driver to find an alternative use for this material. OPG has had inquiries from parties interested in utilizing the ash, but cannot, at present, provide adequate and consistent volumes of ash to sustain such a side-industry. Prior to the conversion of *these generating stations to biomass, some coal ash was reclaimed for asphalt production. The ECA (Environmental Certificate of Approval) under which the Atikokan and Thunder Bay stations currently operate requires the ash to be landfilled, but an amendment to the ECA could be requested if an environmentally safe and economically viable alternative use for the ash were identified.*

5.2.2 Soil amendment

The use of wood ash as a soil amendment in Canada is largely under provincial/territorial control and the process for obtaining regulatory approval to apply ash on forest or agricultural soils differs in each jurisdiction. In many jurisdictions, the approval process is complex and time-consuming, and is frequently cited as a critical barrier to the increased recycling of wood ash in Canada.

Alberta is the only Canadian province with guidelines aimed specifically at the use of wood ash as a soil amendment [3]. In some provinces (e.g., British Columbia, Ontario, Québec, New Brunswick), guidelines developed for soil applications of other residual materials (e.g., municipal biosolids, pulp and paper sludge) also apply to wood ash [23]. In other jurisdictions, wood ash is treated as a hazardous waste, and some form of environmental impact assessment is required to obtain approval to apply wood ash to the soil [23].

Before any approval to use wood ash as a soil amendment can proceed, most Canadian provinces/territories require that it be analysed to determine the concentrations of 11 trace elements (arsenic, cadmium, chromium, cobalt, copper, mercury, molybdenum, nickel, lead, selenium and zinc; [23]). Some provinces require additional analyses to determine, e.g., pH, acid neutralizing value, moisture content, or concentrations of potassium, dioxins and furans, and/or polyaromatic hydrocarbons. This information is used to calculate ash dosage rates and to ensure that applied ash does not cause soil and/or water contamination:

- In Alberta, wood ash dosage rates are determined from the lime requirements of the receiving soil and the calcium carbonate efficiency of the wood ash. The maximum dosage rate for wood ash on agricultural soils in Alberta is 15 Mg ha^{-1} during a single application, and 45 Mg ha^{-1} over a lifetime [3].

- In Nova Scotia, wood ash dosage rates are also determined from the lime requirements of the receiving soil and the calcium carbonate efficiency of the wood ash. A recent study conducted on nine commercially managed farms growing perennial forage crops in Nova Scotia employed one-time wood ash dosage rates that ranged from 5.2 Mg ha^{-1} to 31 Mg ha^{-1} [35].

- In Québec, dosage rates can be calculated using either the trace element concentrations or the acid neutralizing value of the wood ash. The maximum dosage rate on agricultural soils is 22 Mg ha^{-1} over a five-year period, to a maximum of 88 Mg ha^{-1} every 20 years [25].

5.2.3 Other uses

Wood ash generated at pulp and paper mills is used on a small scale at some sites for a variety of other beneficial purposes (Table 5.4). These can include soil stabilization, road stabilization, solidification of waste, and as a neutralizing agent. There are also some possible benefits of using this ash in cement production (e.g., particle size-related), provided that Ca and Mg oxide levels are not too high.

5.3 Improving the use of ash

Policies aimed at promoting the use of wood ash as a soil amendment have encouraged its diversion from the landfill in some provinces.

There are several barriers that must be addressed to further encourage the diversion of wood ash from the waste stream in Canada [24]. These include:

1. Lack of clear, scientifically-supported standards and guidelines for the beneficial use of wood ash.

2. Lack of economic incentive - the costs to obtain regulatory approval, transport and utilize wood ash is often higher than the costs to landfill wood ash.

3. Lack of know-how on ways to protect worker health and safety and ease ash handling and application.

4. Lack of recognition that wood ash has economic value and, consequently, little motivation to maximize wood ash quality by manipulating feedstock characteristics and optimizing combustion conditions.

Perspective from the ground: Ontario Power Generation

In preparation for a future in which bioenergy provides a larger fraction of the electricity mix and produces greater volumes of ash, alternative uses for biomass ash need to be considered. Greenhouse gas emissions aside, the use of bioenergy will be far more sustainable if ash is used beneficially. Key limitations, as identified by OPG, to the increased diversion of wood ash from the waste stream include:

- *A need for demonstration and/or commercial proof of concept projects that can be used to illustrate the productive use of biomass ash and methods of avoiding or mitigating negative environmental impacts.*

- *Insufficient consumer demand for ash; a lack of understanding of its market value and the costs associated with transporting and processing ash for consumer-use.*

- *Lack of institutional confidence and know-how at the regulatory level on how best to manage ash in an environmentally safe manner.*

6 Denmark

Authors: Nicolai Bech (StandardConsult ApS), Birgitte Primdal Dam (Emineral A/S)

This report aims at presenting the status of the situation on the production and use of Bio Mass Ash (BMA) in 2018 in Denmark. It also means that the report is limited to cover ash from sources like wood and straw and therefore excluding other ash products like sewage sludge ash and waste incineration ash or any other ash fraction beyond the primary scope.

There are at the present no statistical sources for quantities of Bio Mass Ash produced so an indirect approach has to be considered in this case.

6.1 Ash sources

In Denmark, biomass ash (BMA) mainly results from combustion of solid fuels like straw and wood.

6.1.1 Current status of biomass combustion

The total energy consumption in Denmark developed substantially since 1972. Figure 6.1. gives an overview of the development.

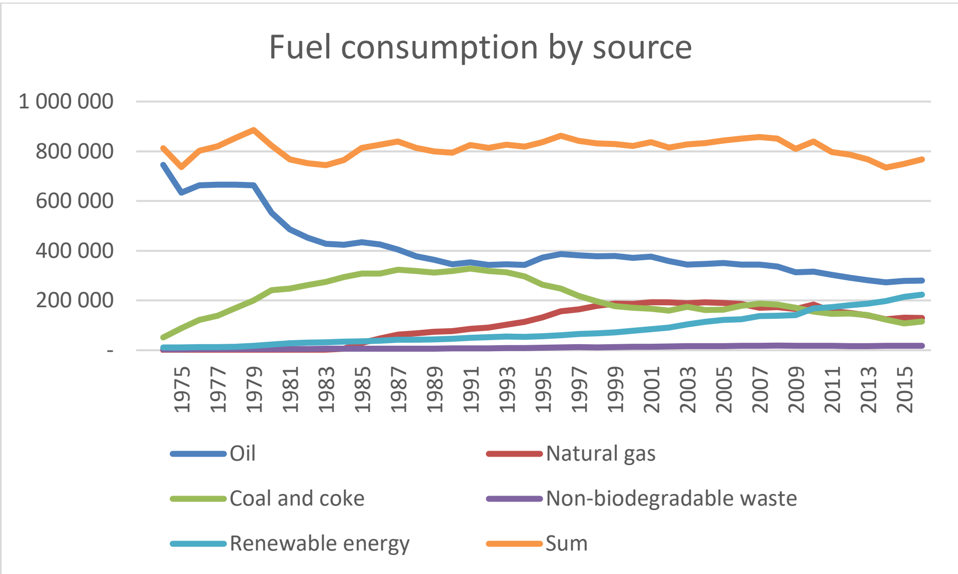


Figure 6.2. Total fuel consumption (TJ) in Denmark since 1972 (Source: Danish Energy Agency 2017)

The gross use of energy in Denmark has not changed significantly since 1972 although different energy savings campaigns has reduced the consumption for heating. The important development has been the wish to introduce more renewable energy in the source mix. Since the beginning of the 1990's there have been a trend to reduce the use of coal and coke. Oil consumption is governed by the need for transportation. However more electricity is foreseen as the potential replacement for oil in the transportation sector.

Table 6.1. The distribution of gross energy sources in 2016 (Source: Danish Energy Agency 2017)

Fuel equivalent	2016
Oil	36%
Natural gas	17%
Coal and coke	15%
Non-biodegradable waste	2%
Renewable energy	29%

To get closer to the relevant issue of BMA a breakdown of the relevant renewable energy is needed:

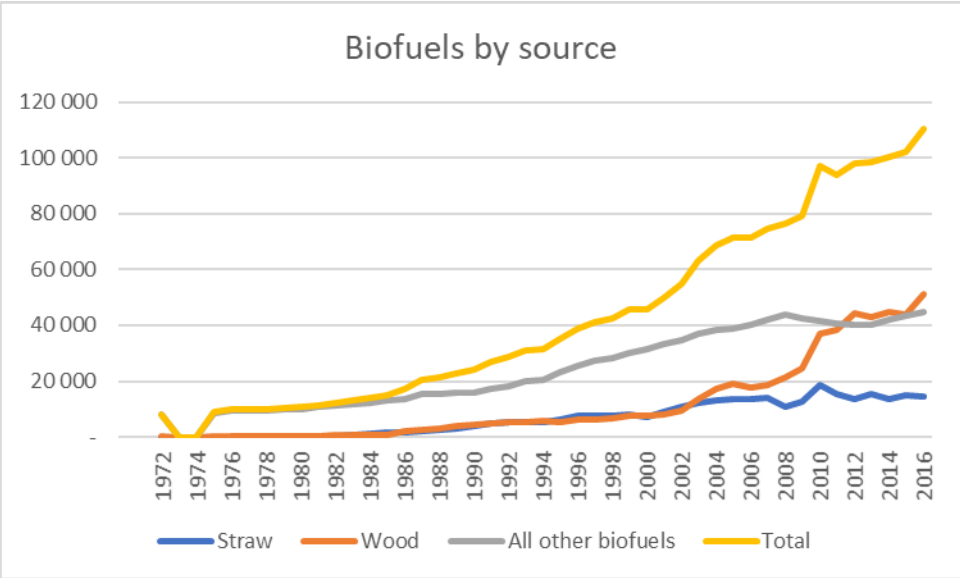


Figure 6.3. Development of the use of renewable energy sources since 1972. All other bio fuels include e.g. household waste, biogas and liquid biofuels. Unit is TJ. (Source Danish Energy Agency statistics for 2017).

Wind energy play a very important role in the complete energy mix. Since there is no fuel nor ash associated with this energy source it is not cared for in the statistics of figure 6.4. The same applies to solar and hydro energy sources. By all other biofuels is understood e.g. biogas from a number of different sources, various liquid biofuels and the use of certain waste sources.

Table 6.2. For 2016 the fuel mix represents a total of 110.000 TJ.

Source	2016
Straw	13%
Wood	46%
All other biofuels	40%

40 % of the fuel mix from the category 'All other biofuels', corresponding to 45 PJ is not resulting in ash formation. This leads to identification of wood (in various forms) and straw as the two biofuels that are really ash producing. It is known that a very limited use of other alternatives like olive kernels, sun flower husk etc. may be used on experimental basis but not to an extent that it is statistically treated separately. Demolition wood is not allowed as a fuel in Denmark and is

therefore not included. By wood is understood various types of virgin wood in forms like pellets or chips.

With this information and assuming an average ash content of 1% in wood with heating value of 16,5 MJ /kg (Danish Energy Agency info, average for various sorts of woody material) and 6% in straw with heating value of 14,5 MJ / kg (Danish Energy Agency info on Biomass Statistics) the annual production of Bio Mass Ash (BMA) will be about 61.000 tons straw ash and about 31.000 tons wood ash. This is the total calculated amount counting all available as well as unavailable sources. The ash is realized in two forms: bottom ash and fly ash.

The different biofuels are used in different types of units. Large scale power stations, different sizes of district heating plants and in a wide range of household (including farms) appliances.

6.1.2 Large scale combustion of biomass

There is an incentive for the use of biofuels in power stations. In the Danish situation a subsidy is available for the production of heat. And also at the large stations there is attention to the best utilization of BMA. Since the 1990's there has been used biofuels in large power stations.

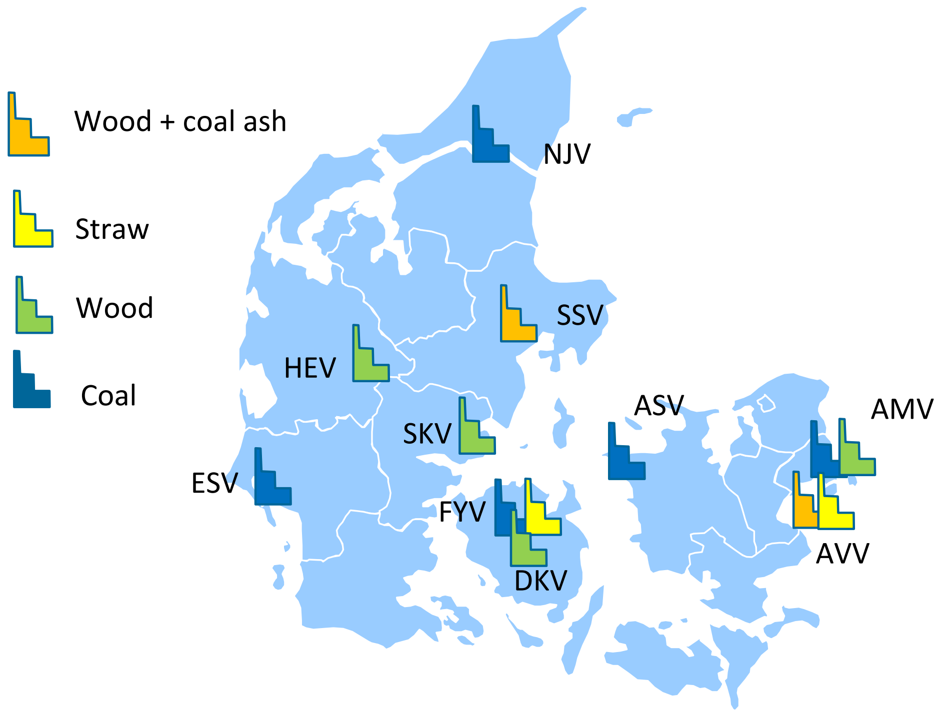


Figure 6.5 Map of Denmark with a marking of the larger power stations. Notice especially the marking of stations using coal ash as an additive. Status as per 2017/2018. Source Emineral A/S.

At the present there is a trend to replace coal fired units with wood fired units and refurbishing former coal fires unit to burn wood. This implies using coal ash as an additive. The resulting fly ash is very useful as concrete additive and therefore this part of the biomass ash is not available as pure BMA and should therefore be subtracted from the statistically available amount. The AMV and ASV stations are working to install fast fluidized bed boilers for the use of wood chips to fully replace the use of coal. These new stations are expected on-stream by 2019.

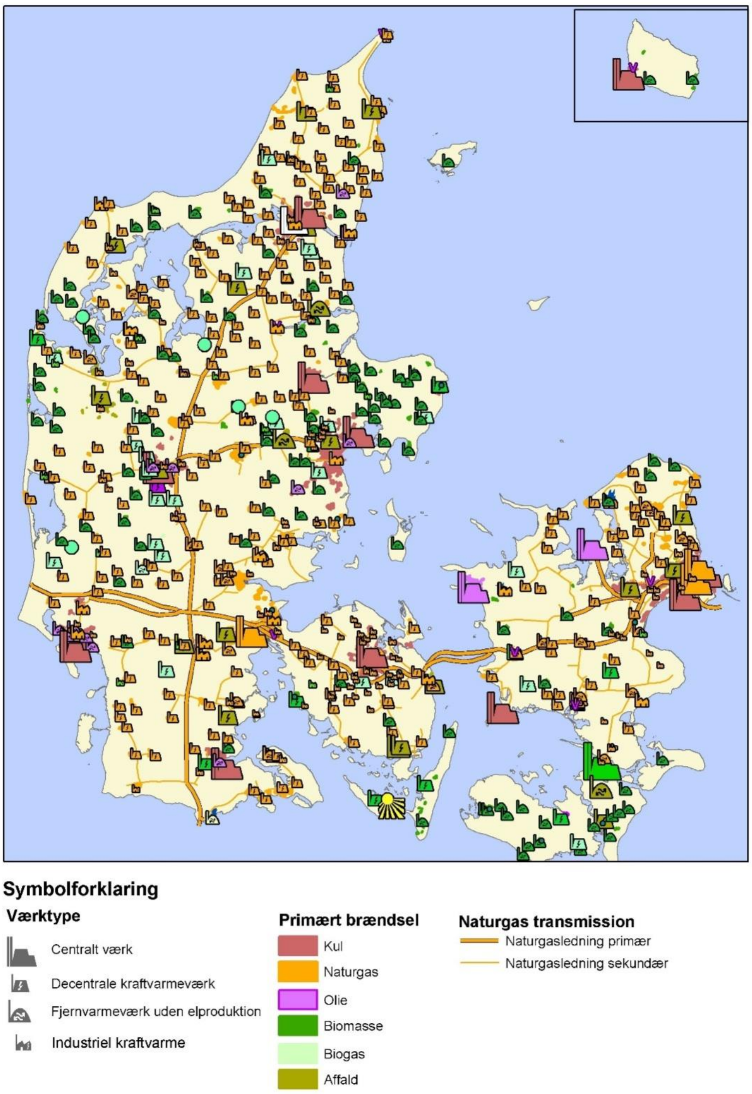
For the large utility stations, the annual production of pure BMA at the present is found in table 6.3.

Table 6.4. Present annual production of pure BMA from large scale production and therefore excluding co-combustion of wood-pellets and coal fly ash. (Source Emineral private communication)

Fuel	Fly ash in ton per year	Bottom ash in ton per year
Wood	6.500- 10.000	8.000-10.000
Straw	2.200 - 3.200	17.000-18.000

6.1.3 Medium-large scale combustion of biomass

Medium scale combustion of biomass (1- 80 MW_{th}) in Denmark is also using mainly wood chips, but also wood pellets and straw as solid biofuels.



:

Figure 6.6 Map of Denmark with indications of district heating plants and other energy converting installations. (ource Rosborg Gymnasium og HF).

Figure 6.7 shows a map of Denmark with indications of the many district heating plants as well as other energy converting installations. The picture is with Danish text but only serves to indicate the widespread use of district heating. Main fuel is natural gas, however they also use certain quantities of biogas, solar and industrial surplus heat. The produced energy is mainly delivered as district heating in the more densely populated areas. For the larger units they are often also power producing installations. In the general picture the district heating is by now more than 50% relying on renewable energy. From the perspective of solid biomasses and therefore relating to the production of BMA using the same assumptions as for already indicated the aggregated numbers can be as depicted below.

Ash from biofuel produced by district heating plants.

Fuel	Ash in tons per year
Wood	4.600
Straw	16.000

Table 6.5. Calculation of ash production per year in average for solid biofuels from district heating stations. (Basic statistical source: Danish District Heating Association).

It is important to notice that as a general rule of thumb all combustion is carried out using grate firing technology and that almost always bottom ash and fly ash are mixed in the process for practical reasons. Also often the stations use a concurrent mix of fuels to optimise the combustion.

6.1.4 Small scale combustion of biomass

Combustion of biomass on small scale plays a certain role in the sense that many households, especially in the country side have wood pellets stoker systems or even straw fired boilers installed. This particularly applies since there is usually no district heating or natural gas available. There is very little knowledge about the use of ashes from these installations. A very likely scenario is that all the ash from these installations is directly spread in nearby fields and is therefore not included in the available ash quantities. Many households also have different types of wood stoves installed not so much as a source for comfort heating but from tradition of "feel good". Ashes from these many installations are completely out of scope for any statistical consideration.

6.1.5 Conclusion of ash production

Bringing all the information above together and disregarding differences between fly ash and bottom ash and assuming that all is accounted for by the preconditions of heat value and average ash content table 6.6 below represents the accumulated information of the annual Danish biomass ash production status 2016-2018. While the straw ash situation is as precise as it can be there is a part of the mentioned small-scale production that is actually used in large stations as fuel co-combusted with ordinary hard coal fly ash as facilitating additive.

Table 6.7. The average Danish annual production of Biomass Ash in tons per year in round figures for the years 2016/2018.

	Wood	Straw
Large station	17,000	20,000
Medium stations	4,500	15,000
Small scale	9,500	26,000
Total	31,000	61,000

6.2 Applications for ash

In Denmark there is a legal order that describes how BMA might be used. This order can be found from the http://standardconsult.eu/links%20and%20biomass%20ash.html homepage translated to English. There is a strong incentive to use the BMA since there is also a tax regulation in place with the consequence of paying about 64 € (475 DKK) pr ton being landfilled (or deposited) rather than utilized. There is almost always a price tag on the utilization route but as a general rule lower than the tax. To lower the cost for utilization there is a strong incentive to support development of new processes.

As a natural consequence landfilling or deposition is very limited and the use of the BMA order play an important role.

Since there are no publicly available sources of information on the use of BMA table 6.8 is the best educated guess for the situation in Denmark.

Table 6.9. The best estimate of the status of utilization of Bio Mass Ash in 2016-2018 (tonnes/year).

	Wood	Straw
Fertilizer	15,000	30,000
Soli improvement	15,000	30,000
Landfilling	1,000	1,000

6.2.1 Fertilizer and soil improvement

The use of BMA for soil amendment or as supplementary fertilizer complies directly with the intension in the Danish Bio Mass Order already mentioned but most certainly also with the EU wish to recycle as much secondary materials as possible (ref: http://ec.europa.eu/environment/circular-economy/index_en.htm).

Soil amendment comes in different forms. The most direct is to simply mix BMA directly with soil by spreading on farmland and then plough the ash into the top soil.

Another way is realized by composting. In this case ash may be mixed with e.g. garden waste or similar from various types of agricultural production and then piled up to “ferment” or undergo natural processes to release nutrients in the mix. At convenient times this mix is the spread on farmland and ploughed down as soil improvement agent and at the same time using the fertilizing potential of the compost. It also provides the benefit of supplying a structure in the top soil.

Use of BMA in forests is still a rather limited utilization partly because of tradition partly because of cost. Only few forest areas in Denmark are used for targeted production of wood. Therefore the outtake is not as extensive as in dedicated production forests. Denmark is mainly an agricultural country.

Both uses are however covered in the BMA order.

6.2.2 Landfill

Landfilling is almost always done as a mean to get rid of ash products that for any reason cannot be utilized directly. The reason could for example be too high concentration of trace elements or even too high content of unburnt. Landfilling is almost only done by large utility stations.

6.2.3 Cement and concrete

In the rare cases of utilization of Bio Mass Ash in concrete it is limited to ash resulting from cocombustion of wood with regular coal fly ash. This is only done in former coal fired units that cannot use wood without the concurrent use of a suitable agent to facilitate the combustion process. Hard coal fly ash is absolutely the best and most obvious agent.

Work is under way to gain acceptance for the cocombusted coal fly ash. As per 2018 it is not brought to the market as an EN 450 cocombustion ash for concrete. However preliminary investigation give reason to believe that the product complies with most of the technical requirements for a durable concrete.

The direct use as cement raw material is limited to the content of Alkalies. In this context straw ash is absolutely out of the question due to the extreme content of Alkalies. Even wood ash is usually too high in Alkalies and the lime content is also a limiting factor.

6.2.4 Asphalt filler

The CEN standard EN 13043 for Aggregates for bituminous filler opens the possibility to use BMA to some extent in asphalt paving. This use is only of interest for wood fly ash. It is particularly the usual high content of lime (hydrated) that is attractive for this particular use.

Although it is a possibility it is hardly utilized in Denmark.

6.2.5 Road construction

Using the known ash fractions for road construction is very limited in Denmark. There is however a minor use for BMA as subbase material for minor quantities of wood ash on parking areas or similar.

6.3 Improving the use of ash

Waste Regulations

At the present BMA is considered a waste. However, the Danish BMA order circumvents many of the problems associated with utilizing waste. As can be read in the BMA order there is a strict insight into the use and dissemination of all BMA in Denmark. So despite the BMA is brought to the market there is no requirement to register the product in REACH (the registration of chemicals in Europe, see details here https://echa.europa.eu/regulations/reach/understanding-reach). If that was required, BMA would most likely not be utilized but just wasted due to the complications involved in handling and using REACH registrations (and all the associated costs).

It is also worth mentioning that the ambiguous interpretation of the waste legislation in all EU countries leads to frustration in the ash industry and not leading to any improvement in the environment at all. It however provides an obstacle for a healthy recycling regime in Europe.

Transport regulations

The current EU regulation on waste shipment (EU regulation http://ec.europa.eu/environment/waste/shipments/index.htm) does not specifically list ashes from biomass combustion as a green list (or even orange list) material by reference to the Basel convention. In this way, biomass ashes are automatically classified as unlisted material. This does not fit with the nature of the material. A classification on the green list would make cross-border transport for utilization less complicated.

The expected change in the fertilizer regulation may change this situation.

Fertilizer legislation

There is an old fertilizer regulation in place (EU Fertilizer order 2003/2003) and implemented in different form in all EU countries. It does not consider the use of recycling material but only chemical NPK fertilizer. A major work to implement a new updated order is under way building on the scientific Strubias project (http://www.refertil.info/news/strubias-working-group).

This work may result in:

- Facilitating the possibility to utilize BMA.
- Easing the cross country transportation by not considering BMA to be waste.
- Circumventing the REACH registration requirement
- And fulfilling the EU circular economy goal.

Since this new order must be implemented in all EU countries it is hoped that the political process can pave the way for a harmonized order meaning that it will be implemented as is in all EU countries and therefore inactivate any existing individual legislation in all EU countries.

6.4 Characteristic of biomass ashes

Since the Danish experience is concentrated on straw and wood the characteristics will concentrate on that.

Straw ashes are from a variety of sources mostly from: wheat, barley, rye, oats, grass and rape. Some of them come both as early and late crops. Since these are all one year crops the analysis of the ashes are almost identical and in any case it is practically impossible to distinguish the individual fuels since they unavoidably mixed in the fuel handling and storage.

Straw ash is mainly characterized by the very high content of Potassium (K_2O) whereas the wood ash is characterized by the high content of Calcium (CaO). In general the most important trace elements are Cadmium (mainly from chemical NPK fertilizer as produced in the past), Chromium and Mercury. It is important to emphasize that in Denmark demolition wood and impregnated wood is not allowed as fuel and therefore other harmfull elements are of low concern.

6.5 Development of recycling processes

The already mentioned high taxes for landfilling etc. in Denmark causes a strong incentive to develop processes to utilize almost all ash fractions. These developments include processes to separate the chemical components in order to utilize the fertilizing components of the ashes. Other processes concentrate on various types of composting either alone or in combination with other recycling materials like garden waste or similar. Also direct use as filler in concrete is under scientific investigation until 2020. Use as filler in asphalt pavings is also considered.

The very high content of Potassium in straw ash has encouraged processes to separate in liquid state the Potassium from trace elements. Such processes exist but the use is not widespread due to the important cost implications.

Due to the increasing interest in sustainable growth philosophy on fields or in forests there is a tendency to place more focus on the recycling of ash as fertilizer. Some forests have a need for supply of lime and micro nutrients whereas farmland fields are more in need for Sulphur, Nitrogen, Potassium and Phosphorous. It is important to always bear in mind that recycling of BMA requires the satisfaction of all parties in the logistic chain.

The high lime content of wood ashes leads to a certain focus on the occupational health and safety aspects of handling large quantities of especially dry wood fly ash. Processes to granulate such materials are available and are tested in Sweden and Denmark. Such granulate is foreseen to have better possibilities both in handling, transportation and final end use for spreading in fields or forests.

6.6 Conclusion

With many years of experience with the use of biofuels and with very high taxes imposed on landfilling there are strong incentives to find meaningful uses of the huge quantities of Bio Mass Ash. That coincides perfectly with the EU wish to recycle all available materials.

With the prospects of moving away from fossil fuels at even greater pace the foreseeable quantities of BMA will increase substantially and the need to identify best solutions is not solved as yet.

To facilitate the future use it is crucially important that the legislative systems (both EU and national governments) aid by easing the acceptance, transportation and taxing of BMA.

7 Germany

Author: Hans-Joachim Feuerborn (VGB)

7.1 Ash Sources

7.1.1 Current status of biomass combustion

Basically biomass is used for energy and heat production. For this, different types of biomass are combusted in different types of boilers. The definition of biomass within the Renewable Energy Directive [62] of the European Union is as follows:

Biomass means the biodegradable fraction of products, waste and residues from biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste.

In Germany, biomass for energy and heat production is considered as [63]:

- *Plants and plant parts and the fuels made from plants or plant parts,*
- *Waste and by-products (vegetal and animal origin) from agriculture, forestry and fishing industry and each downstream processing establishments,*
- *Residual wood from premises of woodworking and processing and the wood based panel industry*
- *Landscape care goods and float ups from waters, shore care and pollution - prevention,*
- *Old wood and waste wood and*
- *Bio-waste.*

For waste wood, the national waste wood act [64] describes four types of waste wood resulting in biomass ash when combusted (see Table 7.1). According to this classification, only waste wood of category A I is considered clean wood and class AI and AII are defined to be for utilization.

Table 7.1: Categories of waste wood according the German Waste Wood Regulation /64/

A I	untreated or mechanically processed scrap wood that was not contaminated with foreign substances while used
A II	glued, painted, coated, varnished or otherwise treated waste wood without halogenated organic compounds in the coating and without wood protecting agents
A III	waste wood with halogenated organic compounds in the coating and without wood protecting agents
A IV	waste wood treated with wood protecting agents, e.g. railway sleepers, electricity poles … (except waste wood with PCB content)

7.2 Biomass for electricity production

Renewable power production in Germany has increased tenfold with implementation of the renewable-energy-act [65]. In 2016, about 31.7 % of the gross power production was produced by renewables and 8.6% of this by biomass alone. The power production from biomass increased from 44.6 TWh in 2012 to 51 TWh in 2016 [66]. In 2017, about 51.4 TWh were produced by biomass which represented 8.5% of the gross energy consumption. The production by biomass is based on biogas (32.5 TWh, +1.9 % compared to 2016), solid biomass (10.6 TWh, -1.3 % compared to 2016) and by the biogenic part of waste (5.9 TWh, -0.4 % compared to 2016) [67].

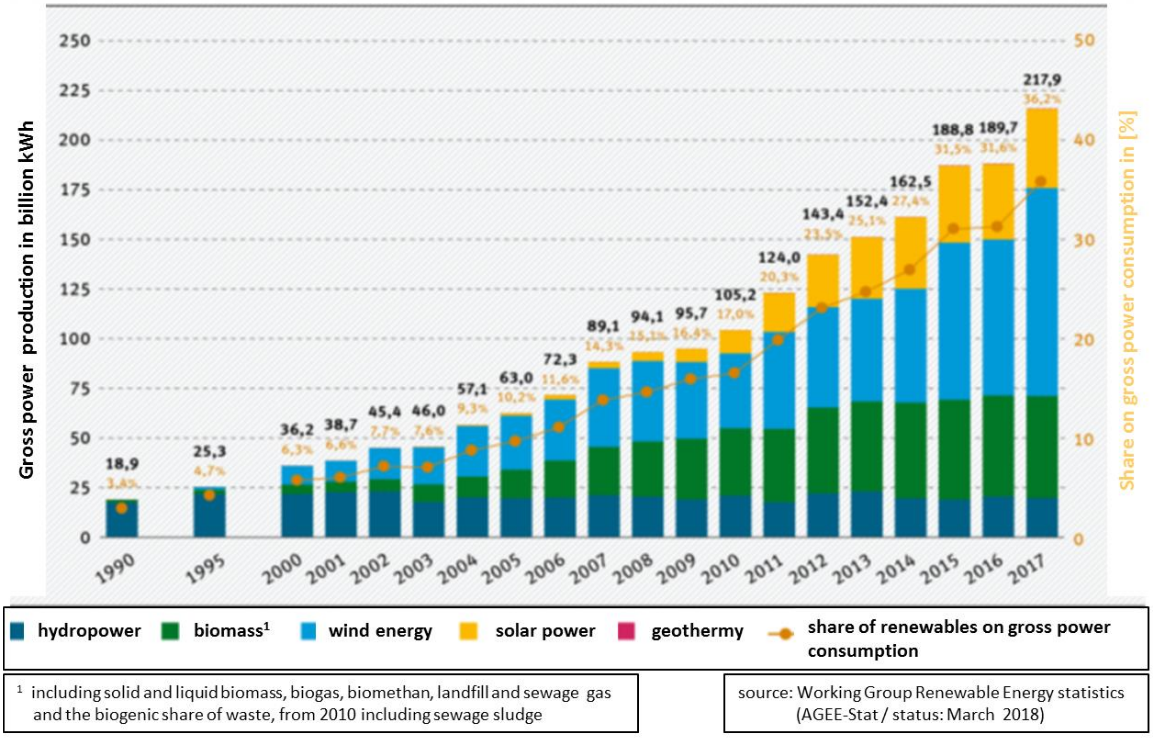


Figure 7.1 Development of the energy production by renewables in Germany [68]

7.3 Biomass for heat production

The share of bioenergy on the total energy consumption for heat in Germany was 11.3 % (140.6 TWh). With 87 % of all renewables biomass will remain the most important source for heat production. For the heat production solid fuels like wood, liquid fuels like plant oils, gaseous fuels like biogas from manure and energy plants as well as sewage and landfill gas, and the organic part of municipal waste is used (see Figure 7.1) [69].

Micro units operated with log wood and wood pellets are predominantly operated in private households for heat production. The units are mostly modern electronically controlled and fully automatically gasification or wood pellet boilers. For this, wood pellets from natural compressed residual wood are used. The pellet combustion units replace conventional oil heating systems. Plants of bigger size (from 100 kWth) are used for heat supply to bigger properties, several buildings or city quarters. For this mostly wood chips are used and in some cases also straw [70,71].

In Germany, about 0.7 million small units for solid fuels exist, in addition about 11.7 million single-room-heating systems as fire-place or cockle-stove fired with coal or wood [72]. Furthermore, there are about 380 wood-fired district heating plants [73] which are partly fired with waste-wood of classes A1-A4 (see Table 7.1). In the large combustion plants (about 600 with

> 50 MW) mostly burn coal and lignite is combusted and biomass is sometimes used in co-combustion.

With the most recent published raw materials monitoring report for wood [74] detailed information is given on the types of wood used in large (> 1MW) and small (< 1MW) units wood-fired units in 2016. Based on the biggest share in large units is with waste wood in a total amount of 6.5 Mio t (48.6%). In addition by-products from sawing (0.8 Mio t) and industrial residual wood (0.6 Mio t) sums up to 10.8 %. Of importance is forest residual wood with 1.6 Mio t (12.2%) (see Figure 7.3a).

In the small units (< 1 MW) the most important wood types are forest residual wood (31.4%), by-proucts from sawings (18.4%), landscape preservation wood (15.9%), forest lumber wood (13.7%) and pellets/briquettes (7.3%) (see Figure 7.3b).

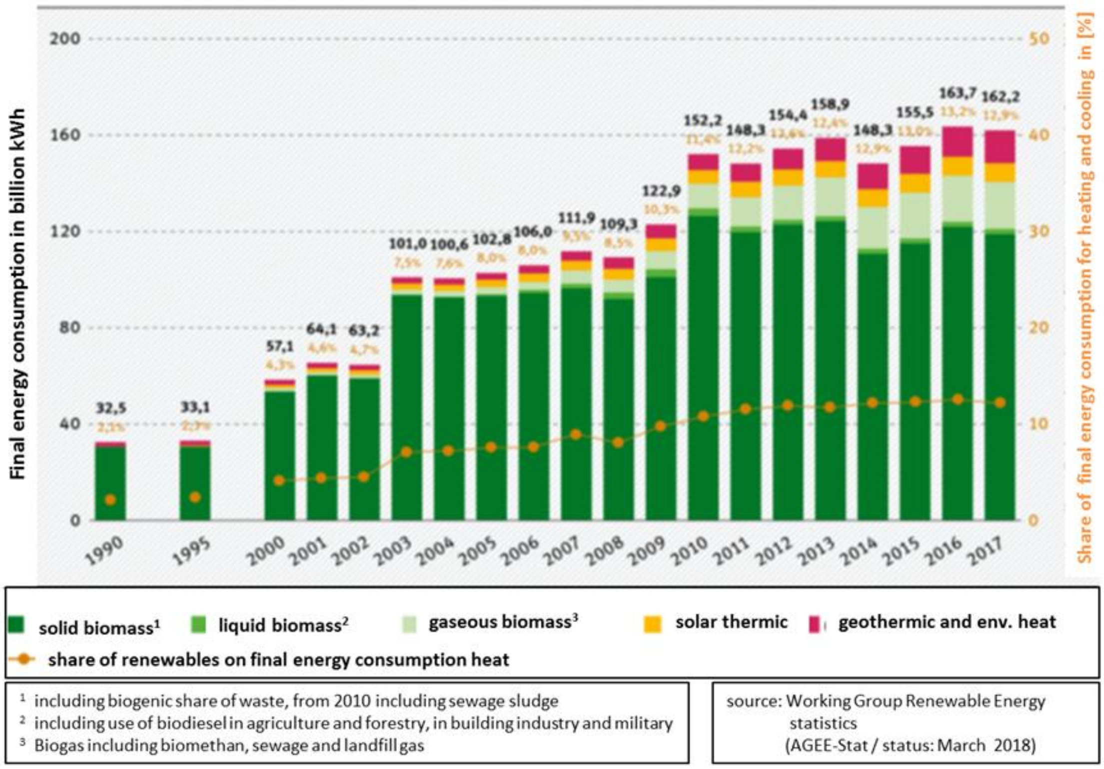
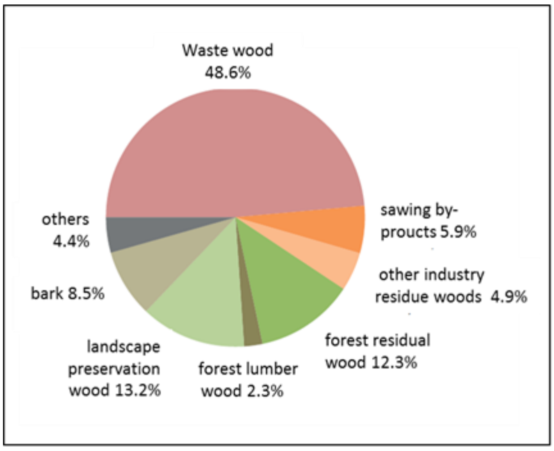


Figure 7.2 Final energy consumption for heat from renewable energies in Germany [68]



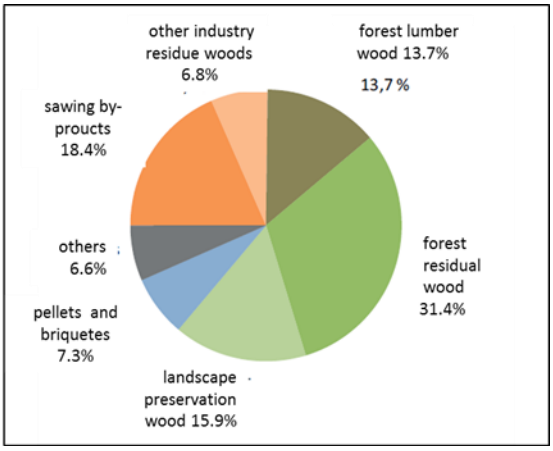


Figure 7.3a Share of wood types in wood-firing plants > 1MW total amount: 13.3 Mio t /74/

Figure 7.3b Share of wood types in wood-firing plants < 1MW total amount: /75/

7.3.1 Relation to ash production and properties

The ash amount is very much dependent on the wood type, the amount of bark, leaves and cuttings. In addition, the combustion technology is of importance. There are no official statistics on the production of biomass ash and on the use of fuels in specific types of boilers. Only on biofuels statistical data exist [74,76]. The published data on waste wood and wood used in energy production allow calculation of the produced ash amounts.

Considering an amount of waste wood of 6.5 Mton [74] and a global ash content of 10 % for waste wood the resulting ash amount is 650 kton.

With an amount of 13.3 Mton [74] of wood used in large (>1 MW) combustion plants and of 6.5 Mton used in small (<1 MW) combustion plants and considering a global ash content of 2% for all wood types the resulting ash amount for wood is about 400 kton.

Independent of the correct calculations for use of more wood without bark, and considering the amounts of ash produced in households and with other types of biomass (e.g. straw) is not included this figures demonstrates that the total amount of biomass ash in Germany can be assumed to be more than 1 Mton.

The properties of biomass ash are very much depending on the fuel type and the combustion technology. Basically physical and chemical properties have to be considered for the evaluation of properties. The physical properties (morphology, grains size, density,..) are very much depending on the fuel, its preparation and the feeding system. The chemical properties are very much depending on the type of fuel and in case of wood also from the region of growth impacting the trace element concentration in addition to the impurities caused by harvesting, processing and combustion.

As the ash is mostly considered a waste material the requirements for the disposal act [77] has to be considered which are content and leaching limit values for organic and inorganic parameters and especially the loss on ignition. That can also be seen as a starting point for available information on properties. In addition, requirements on macro- and micro-nutrients for the application as or in fertilisers are partly published. Properties are also reported in some basic research work .

7.4 Applications for ash

There are no specific federal or regional statistics on the use of biomass ash in different fields of applications. Also the waste statistics can also not be used as the EC codes used for biomass ashes are also covering ashes from other fuels (e.g. coal). However, for some fields of application specific information on a regular use and respective regulations exist.

7.4.1 Fertiliser in forestry and agriculture:

Biomass – or better wood – ashes are regularly used as or in fertilisers and are also used for forest liming. For this, only untreated wood has to be considered and the requirements of the fertiliser act [78] have to be met. This act also covers the application as fertiliser in agriculture.

In Bavaria, a special guidance on the use and disposal of wood ash has been prepared [79]. In Baden-Württemberg a quality mark exist for the use of a mixture of Dolomite and wood ash for forest soil protection liming [80]. Two levels of quality control systems for wood ash are established in Germany: The control of wood ash and a Dolomite-wood ash mixture, particularly designed for the use in forests, performed by the forest administration of Baden-Wuerttemberg in co-operation with limestone plants and the free RAL quality mark which is organized by the Federal Quality Association for Wood Ash [81].

7.4.2 Infill

Depending on the regional situation biomass ash is used for the infill of underground mines. For this the requirements of the decree about the use of waste for underground mine fill [82] have to be considered.

7.4.3 Disposal

All ashes resulting from Waste Wood Combustion classes A2 to A3 are disposed of in mostly underground disposal sites due to hazardous properties. For wood ashes with non-hazardous properties also disposal sites with less strict requirements can be used [77].

7.5 Improving the use of ash

There are several aspects to be considered to improve of ash. They are of legal and of technical nature. The legal aspects address the legal clarity when mixing biomass ash as waste materials to obtain a product with specific properties. Clarity is needed on how to handle the ban of waste mixing.

The technical aspects for biomass ash start already with the improvement of the quality in the power plant/combustion unit. There are a few research projects now also addressing this aspect, e.g. [83].

But also processing of ash is of importance, either to improve the properties (e.g. homogeneity) or the environmental performance (availability of nutrients or leaching behaviour).

8 Italy

Author: Roberta Roberto (ENEA)

8.1 Ash sources

8.1.1 Current status of biomass combustion

The total gross final energy consumption in Italy in 2015 was 121.7 Mtoe, of which 21.3 Mtoe from renewable sources, corresponding to 17.5%[55]. The highest share of renewables was in the Electricity sector, as shown in Table 8.1.

Table 8.1 Total gross final energy consumption per sector(2015)

Sector	Total gross final energy consumption [ktoe]	Total gross final energy consumption from RES [ktoe]	Total gross final energy consumption - RES share
Electricity	28,198	9,435	33.5%
Thermal	55,753	10,687	19.2%
Transport	33,063	2,121	6.4%
Total	121,705	21,286	17.5%

In the Electricity sector 19.4 TWh (1665.2 ktoe) was from bioenergy production, of which 6.3 TWh (540.9 ktoe) from solid biomass (including the biological fraction of Municipal Solid Wastes - MSW)[21]. In the thermal sector 6624.2 ktoe was produced from direct use from solid biomass, 568.5 ktoe was produced as derived heat from CHP plants fired with solid biomass and MSW, and 70.2 ktoe was produced as derived heat from thermal plants fired with solid biomass.

The trend from 2012 to 2015 in the thermal energy production from solid biomass per sector and type of plant is shown in Table 8.2.

Table 8.2: Thermal energy from solid biomass[21]

	2012	2013	2014	2015
	[TJ]	[TJ]	[TJ]	[TJ]
Direct consumption	279,829	181,558	244,494	277,342
residential	277,893	277,698	237,623	267,682
industry	980	2,300	3,489	6,110
services	888	1,485	2,488	2,119
agriculture	67	75	894	1,431
Derived heat	17,423	25,151	28,388	26,740
from CHP plants[1]	14,345	22,059	25,672	23,800
from thermal plants	3,078	3,092	2716	2,940
Total	**297,252**	**306,709**	**272,882**	**304,082**

The contribution from wood logs and pellets in the residential sector, that in Italy plays a great role in the consumption of wood biomass for heat production, is given in Table 8.3.

Table 8.3: Thermal energy from wood logs and pellets in the residential sector [21]

	2012	2013	2014	2015
	[TJ]	[TJ]	[TJ]	[TJ]
Wood logs	250,565	245,470	207,785	232,436
Pellet	25,511	30,503	27,990	33,490
Other	1,817	1,725	1,848	1,756
Total	277,893	277,698	237,623	267,682

Large scale combustion of biomass

In Italy there are less than ten large scale plants (> 200 MW_{th}) running on wood biomass, co-combustion and municipal solid waste. The largest plants are old coal plants in Sardinia region that have been repowered for co-combustion with coal and solid biomass. One plant (345 MW_e) is fired with up to 15% biomass, the other 3 plants (327 MW_e, 327 MW_e and 40 MW_e) are fired with up to 5% biomass [21].

Medium-large scale combustion of biomass

In Italy there are more than 30 medium scale (50- 200 MW_{th}) biomass combustion plants, including wood-biomass and municipal solid waste. The majority of these plants is located in the central and south regions.

Small-medium scale combustion

In the small-medium scale range (5-50 MW_{th}) there are more than 100 plants for CHP or power

[1] Including the amount of heat produced from the bio share of municipal solid waste

production, fired by solid biomass (wood, pruning, residues, etc.) or MSW. The majority of them are CHP plants coupled with ORC units. There are also a number of plants feeding DH systems, for heat production only.

Small scale combustion of biomass

There are more than 250 plants for CHP or electric production in the small scale range (<5 MW_{th}). Among them a few gasification plants, while the majority of plants are biomass-fired boilers coupled with ORC systems.

In the small scale range there are also plants for heat production only that feed DH systems (fired by wood, pruning, residues, etc.) and plants and appliances mainly for residential heating (fired by chips, pellet or log wood).

8.1.2 Relation to ash production and quality

The quantity of ashes produced from wood biomass combustion in Italy has been estimated from the available data on the wood biomass used in: residential appliances and plants[1]; thermal plants for DH[16]; CHP plants and power plants for electricity production[22].

The quantity of ashes from co-firing is estimated from the available data on the power plants fed by wood and coal. It is a rough estimation, based on the data declared in the authorization phase and on assumptions on the quantity and quality of the biomass used (no real data are available on the actual operation of the plant).

Table 8.4 Ash produced from biomass combustion and co-combustion in Italy[2]

	Ashes [t/y]	**Bottom ashes** [t/y]	**Fly-ashes** [t/y]
From wood-fired power plants	613,704	368,222	245,482
From wood-fired DH and thermal plants	12,704	7,200	4,800
From wood-fired residential heating plants and appliances	268,171	268,171	-
total	**894,579**	**643,593**	**250,282**
From co-combustion plants	8,117	4,870	3,247
Total (combustion + co-combustion)	**902,696**	**648,463**	**253,529**

[2] Source: elaboration from the data sources cited [1,16,22] and on hypothesis from the author based on literature reference values on biomass moisture and ash content, annual hours of operation of the plants, bottom and fly ashes ratios

8.2 Applications for ashes

Current applications for ashes in Italy are limited by the National Regulation. The management of ashes from biomass-fired combustion plants in Italy is regulated by D.lgs. n. 152/2006. These ashes are classified as "special wastes" (not hazardous or hazardous) under the EWC codes for process 10 (wastes from thermal processes) and specifically under chapter 10 01 (wastes from power stations and other combustion plants, except code 19).

As wastes, ashes from biomass-fired plants need to be managed by authorized entities. They are usually recovered for other usages or disposed in landfills as wastes. Some quantities are used for cement production, as asphalt filler and in other sectors, following the specific procedures for the recovery and use of wastes specified in D.M. 186/2006 under the following categories:

a) production of concrete, uses in cement or bricks factories;

b) compost production;

c) fertilisers production (compliant with L. 19 ottobre 1984, n. 748);

d) environmental recoveries, according to specific prescribed tests

According to D.lgs. 220/95 (which has transposed the reg. CEE 2092/91) ashes from virgin wood can be used in organic farming as products for fertilization and soil amendment.

Recently, a new category of organic fertilisers has been defined in "D.M. 12 agosto 2016" as "separated fraction from solid digestate and ashes from virgin wood biomass combustion".

Bottom ashes from domestic appliances and small scale residential plants are usually: disposed as organic waste; disposed as waste; directly used in own gardens (land spreading or composting). While bottom and fly ashes from heating plants and power plants (both biomass and co-firing) are usually: disposed (landfills); used for cement production (see details in Table 9.2); used for asphalt filler.

In 2014 about 10% of ashes was disposed in landfills, about 53% was used for material recovery and the remaining part was exported [32].

Table 8.5 Material recovery (R2 to R12) from ash [32]

EWC classification		[t]	[%]
100101	bottom ash	209,848	20%
100102	coal fly ash	602,962	56%
100103	fly ash (from peat and wood)	66,195	6%
100104*	bottom ash (dangerous)	n.a.	n.a.
100114*	bottom ash (from co-inc.)	n.a.	n.a.
100116*	fly ash (dangerous)	n.a.	n.a.
100117	fly ash	195,140	18%
total		1,075,790	

8.2.1 Landfill

Ashes from biomass combustion are disposed in landfills as "special wastes" (not hazardous or hazardous). In 2014 in Italy 186,383 t of ashes[3] from biomass and co-combustion plants was disposed in landfills [32], corresponding to about 10%.

8.2.2 Cement and concrete

The biomass ash from different plants is used as raw material for the production of clinker to be used in cement. More details about the quantity used for cement production are in the following table.

[3] EWC codes: 100101, 100102, 100103, 100104*, 100114*, 100116*, 100117, 100118*, 100119

Table 8.6. Ashes used for cement production (2015)[2])

Description	CER code	Quantity [t/y]
bottom ash, slag and boiler dust (excluding boiler dust mentioned in 100104)	100101	39,692
coal fly ash	100102	277,817
fly ash from peat and untreated wood	100103	550
calcium-based reaction wastes from flue-gas desulfurization in solid form	100105	163,638
bottom ash, slag and boiler dust from co-incineration other than those mentioned in 10 01 14[4]	100115	40,655
fly ash from co-incineration other than those mentioned in 10 01 16 [5]	100117	48,209
sludges from on-site effluent treatment other than those mentioned in 10 01 20	100121	463

8.3 Improving the use of ash

The main limiting factor in Italy for further recovery and usage of ashes from biomass combustion derives from the complex procedures required by the legislation in force on wastes and waste management. A new legislation is needed to regulate the use ashes from wood combustion for fertilization and soil amendment. Moreover, the classification of ashes from biomass combustion and co-firing as wastes is a limiting factor for their re-use even for current and proven applications.

Several studies have been conducted on the feasibility of recovery and use of the ashes from biomass and co-firing and their use as fertiliser and liming agent. Among the others, at the national level: the BIOCEN Project (2004) with detailed analyses on the technical and economic feasibility of the use of ashes as soil fertiliser and liming agent, on ashes composition and characteristics, on prescription and good practices.

---

[4] to be verified if co-firing of wastes is included

[5] to be verified if co-firing of wastes is included

9 The Netherlands

Authors: Angelo Saraber (Vliegasunie), Marcel Cremers (DNV GL), Frans Lamers (DNV GL)

9.1 Ash sources

9.1.1 Current status of biomass combustion

The total energy consumption in the Netherlands was 3040 PJ in 2015. Almost 6% was from renewable sources, corresponding with 119 PJ. About 2/3 (4%) was from biomass, corresponding with 81 PJ (see Figure 9.1). The share of renewables is planned to increase to 14% in 2020 whereby an important role will be for wind and biomass. Only a small part of the biomass can be supplied by inland production. The major part of it has to be imported from sources abroad (wood pellets), which will be co-fired in coal-fired power stations.

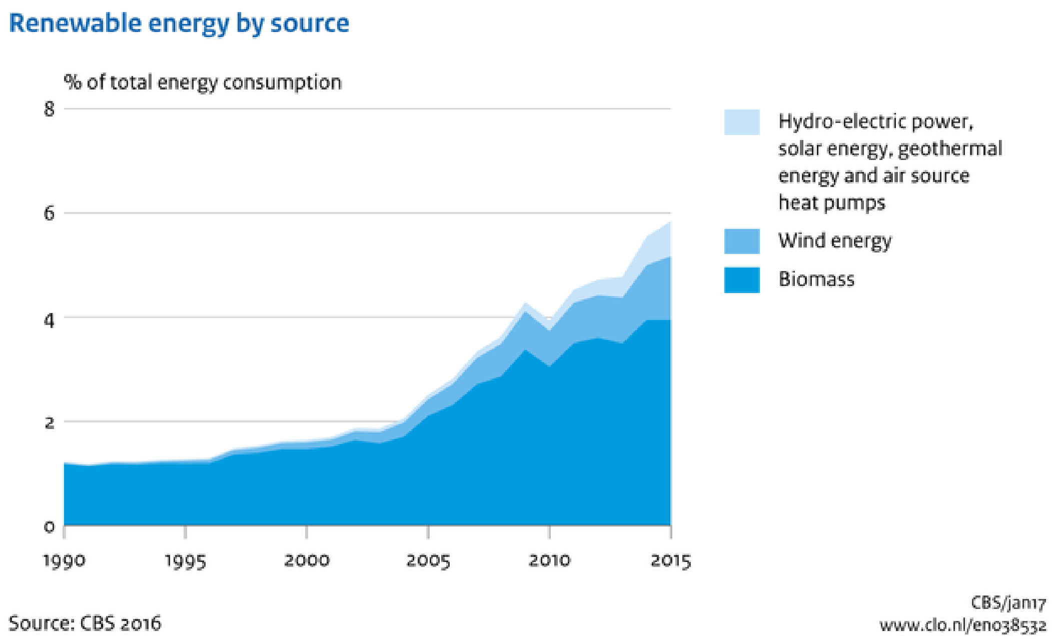


Figure 9.1 Contribution of renewable energy to the total Dutch energy consumption [11]

<u>Large scale combustion of biomass</u>

Subsidies and permissions have been provided by the Dutch government to proceed maximization of co-combustion of biomass for heat and power generation in the Netherlands. Amer power station (about 600 MWe) now is at a level of 5% co-combustion but will start 50% m/m co-firing of biomass by end of 2017. This will increase to 80% m/m in 2019. Also, at Eemshaven power station (1560 MWe) biomass will be co-fired (15% e/e) in the future [54]. At present, Maasvlakte power station co-fires about 8% m/m biomass, which will increase to 35% m/m in 2019. Effectively total use of biomass pellets in coal fired power plants is planned to grow from 850,000 tonnes in 2015 to more than 4 million tonnes in 2019. A part of these co-combustion ashes that will be generated because of that cannot be utilized in cement industry and concrete because it does not comply with the European standard for fly ash in concrete EN 450 (see under the description of the utilization)

Medium-large scale combustion of biomass

Medium scale of combustion of biomass (50- 200 MW_{th}) in the Netherlands covers several types of biomass:

- Demolition wood in five bio energy plants (3 fluidised bed boilers and 2 grate-fired boilers). In one of those plants demolition wood is combusted together with some other biomass.
- Poultry dung in one bio energy plant BMC (fluidised bed boiler).

Remark: Municipal sewage sludge is incinerated in two plants in the Netherlands (fluidised bed boilers). Due to its water content the nett energy production is small.

Small-medium scale combustion

Small-medium scale combustion (5-50 MW_{th}) of biomass is performed in several small – medium size plants. These plants are operated with clean wood fired in grate furnaces (Purmerend, Lelystad, Sittard, Goor) or paper sludge un fluidised bed boilers (Renkum, Duiven).

Small scale combustion of biomass

Combustion of biomass on small scale plays a minor role in bio energy.

9.1.2 Relation to ash production and quality

Table 9.1 provides an overview of the production of biomass ashes and co-combustion ashes.

Table 9.1 Generation of ashes from combustion of biomass and biomass with coal [kton]

Fuel	Bottom ash	Fly ash	Mixed	Sum	Fraction (%)
Demolition wood	21	14	-	35	15
Sewage sludge	-	58	-	58	25
Poultry dung	5	55	-	60	26
Paper sludge	-	73	-	73	31
Clean wood	2	1	5	8	3
total	28	201	5	234	100
Coal+ biomass*	60	430	-	490	

* This is the total ash content from coal fired plants that have 5 – 15% of clean wood as co-combustion

9.2 Applications for ash

Table 9.2 provides an overview of the utilization of ashes from biomass combustion in the Netherlands. At present, fly ash from co-combustion fulfils the same quality standards as ashes from 100% coal and are completely used in cement and concrete. Furnace bottom ash is completely used in civil engineering and in concrete blocks.

Table 9.2 Utilization of biomass ashes in the Netherlands (excluding co-combustion)

Utilization	Amount [kton]	Fraction [% m/m]	Remark
Landfill/disposal	3	1	
Cement and concrete	10	4	
Soil amendment	55	24	Ashes from poultry dung
Asphaltic filler	39	17	Mainly ashes from sewage sludge combustion
Underground mining	31	13	
Civil engineering	19	8	
Other building materials[a]	73	33	ashes from paper sludge combustion
unknown	4	2	
Total	234	100	

a) Including flue gas sorbents

9.2.1 Landfill

In the Netherlands, the so-called *minimum standard for removal* of waste is disposal. This means that that there is no ban on disposal on a landfill for biomass ashes. Despite this only a very small amount is landfilled.

9.2.2 Cement and concrete

The biomass ash of one small bio energy plant (clean wood) is used as raw material for the production of Portland clinker, which is the basis for most type of cements. However, the cement production plant will shut down its clinker production by July 1st 2018. The requirements for this application are not established in standards but in contracts.

The application of biomass ash in blended cements is not practiced as the European standard for cement (EN 206) does not allow this type of ash to be used as compound.

Coal fly ash from co-combustion is used in concrete, both structural and non-structural. According to the European standard for fly ash in concrete (EN 450), it is allowed to co-fire green wood up to 50% m/m fuel based if no other fuels are co-fired. If other fuels are co-fired the maximum co-combustion percentage is 40% m/m fuel based and 30% m/m ash based. There is also a limitative list of fuels which may be co-fired (see table below). As can be seen from the list, ashes from more than 50% co-combustion (such as Amer power plant plans to do after 2017) cannot be utilized as a filler for Portland cement.

Table 9.3 Exhaustive list of allowed fuels that may be cofired for use of flyash in Portland cement

1	Solid Bio fuels conforming 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

9.2.3 Soil amendment and fertiliser use

There are no specific Dutch regulations for the use of biomass ash or wood ash in forestry. This means that the use in forestry has to be qualified as *Dispersion of waste*, which is forbidden. The use of biomass ash as fertiliser in agriculture should be in conformity with the Dutch fertiliser Law. The use of waste streams as fertilisers is only allowed if it fulfils the legal requirements, especially regarding the maximum concentration of heavy metals and arsenic. This concentration has to be attributed relative to the content of one fertiliser compound in the fertiliser/waste. So, a choice has to be made for fertilizing based on CaO, K_2O or SO_3. This is logic for mono-constituents (like FGD gypsum). Biomass ash contains a wide spectre of compounds with fertilizing properties. As only one fertilizing compound can be chosen, concentrations of heavy metals relative to this compound are high and biomass ash is not able to fulfil the regulations in the Netherlands.

9.2.4 Asphalt filler

In the Netherlands, fillers are added to asphalt mixtures to improve the properties of the bitumen. Most asphalt aggregate is river-dredged material, which contains a too small fraction of fine material. This is compensated by the addition of fillers, prepared from different types of fly ashes and limestone. In the Netherlands common ash types used in asphalt concrete fillers are municipal solid waste incinerator fly ash, sewage sludge ash and biomass fly ash.

9.2.5 Underground mining

A part of ashes from the combustion of sewage sludge and waste wood is used for filling of underground mining cavities in surrounding countries.

9.2.6 Road construction

Bottom ashes from several bio energy plants using waste wood are mixed with incinerator bottom ash which is regularly used as road construction base material (embankment material, road foundation material etc.)

9.2.7 Other building materials

Ashes from combustion of paper sludge are used as a raw material / intermediate product for industrial construction materials, cement replacement in building products and desulphurization sorbents.

9.3 Improving the use of ash

Waste Regulations

The present Dutch regulations do not allow recycling of wood ashes in the forests as it is seen as dispersion of waste. An allowance to use biomass ashes as soil amendment in forests and an end of waste classification of biomass ashes for this purpose would remove one of the bottle-necks for ash recycling.

Transport regulations

The Basel Convention is implemented in the EU regulation on shipments of waste and regulates the cross-border transport of waste. This regulation does not specifically list ashes from biomass combustion as a green list material. In this way, biomass ashes are automatically classified as an orange list material, which is the most stringent category. This does not fit with the nature of the material. A classification on the green list would make cross-border transport for utilization less complicated (procedures, administration).

Fertiliser legislation

The requirements of the Dutch fertiliser legislation cannot be met by biomass ashes due to the stringent requirements and the calculation method. A modification of the requirements and the calculation method would be helpful to provide an entry to soil amendment/fertiliser market.

Innovations

The use of wood ash and biomass ash in building materials is hindered by the presence of alkalis and sulphur, which are mostly undesired components. Improvement of the use of wood ash by developing a new Cementous binder, using wood ash as activator for blast furnace slag were not successful.

10 Sweden

Authors: Kent Davidsson, SP Technical Research Institute of Sweden

10.1 Ash Sources

10.1.1 Current status of biomass combustion

In 2012 the total production of ash from combustion in Sweden was 1 700 900 tons, of which 241 900 tons came from combustion facilities in the wood and pulp industries,[4,53] and the rest from the heat and power industry. The sources of the latter is summarised in Table 10.1.

Table 10.1: Sources of ash from the heat and power industry given in tons dry matter.[4]

Fuel	Bottom ash	Fly ash	Other	Sum	Fraction (%)
Solid biomass	153600	101100	600	255300	18
Liquid biomass	0	300	0	300	0
Demolition wood	20600	9700	0	30300	2
Solid waste	774000	148800	58900	981700	71
Other[a]	62200	46900	5000	114100	8

[a] waste, peat, coal and other

10.1.2 Relation to ash production and quality

Solid waste and solid biomass constitute almost 90 % of the sources of ash. While waste may contain some 30 % fossil carbon it is not so clear how much of the ash that emmanates from fossil sources. Probably this fraction is considerably smaller, since the fossil fraction of waste typically consists of plastics which doesn't give rise to much ash. Rather it is uncombustible waste such as glass, sand, metal pieces that end up in the ash.

10.2 Applications for ash

Table 10.2 shows the use of ash in Sweden in 2012. The one dominating use is landfill covering. The term "other" covers a number of uses, none of which exceeds 5 % of the total.

Table 10.2: Utilisation of ash given in tons dry matter.[4]

Utilisation	Amount	Fraction (%)
landfill covering	997200	68
landfill	147400	10
export	65800	5
other[a]	248600	17

[a] road construction material, return of ash to forest, and other

10.2.1 Landfill

Landfill only constitute some 10 % of the total use of ash. Instead ash is mostly used for covering of old landfills. Most landfills are likely to have been covered before 2030, why alternative utilisation of the ash will be increasingly desired.

10.2.2 Common practice and limitations

A lot of the ash comes from combustion of forestry products (stem wood, bark, branches etc.) This ash can be returned to the forest if it has not been contaminated. There is a potential to increase this kind of use of the ash. The Swedish Forest Agency recommends that ash be returned to the forest to mitigate acidification[56]. Returning the ash is considered especially important if a major part of the needles are removed when collecting the biomass, if the soil is strongly acidic or the soil is peaty. The ash, of course, has to fulfil certain standards. Table 10.3 shows recommended concentrations of elements in ash intended for spreading in the forest.

Table 10.3: Recommended concentrations in ash for spreading in forests.[56]

	Limits	
	minimum	maximum
Nutritiens (g/kg dry ash)		
Kalcium	125	
Magnesium	15	
Potassium	30	
Phosphorus	7	
Trace elements (mg/kg dry ash)		
Boron		800
Copper		400
Zink	500	7000
Arsenic		30
Lead		300
Cadmium		30
Chromium		100
Mercury		3
Nickel		70
Vanadium		70

10.3 Improving the use of ash

The major source of information to ash-related questions in this contest is Swedish Energy Ashes (Svenska Energiaskor AB) [28]. Swedish Energy Ashes is owned by ten Swedish energy companies. Its mission is to favour environmentally sound, resource-efficient and economical use of the ash. One of its business is referrals to suggested legislation, regulation and governmental recommendations for the handling of ash.[28] The following is based on such referrals.

From a general point of view there is a national environmental goal[29] of toxic-free environment that has to be balanced with the goal to recycle material. The latter favours several of the other national environmental goals. As for ashes this means:

- Ash should be used.
- Toxic constituents of the ash should not be spread.

Most referrals by Swedish Energy Ashes concerns this balance, but also unclarities and bureaucracy regarding the legislations.

An explicit policy from the authorities to save natural resources is missing. Ash is a partly forgotten resource.

11 References

1. AIEL, 2015 (Italian Agriforenergy Association, www.aiel.cia.it)

2. AITEC, see http://www.aitec-ambiente.org/it/Recuperorifiutiincementeria/Recuperodimateria/tabid/127/Default.aspx

3. Alberta Environment. 2002. Standards and guidelines for the use of wood ash as a liming material for agricultural soils. Available from: http://environment.gov.ab.ca/info/library/6680.pdf [Accessed 22 July 2016].

4. Askor i Sverige 2012, Svenska EnergiAskor, Statistics Sweden, http://www.energiaskor.se/pdf-dokument/overgripande%20rapporter/Askor%20i%20Sverige%202012.pdf

5. BIERMAYR et al. (2017): Innovative Energietechnologien in Österreich - Marktentwicklung 2016 Hrsg.: Bundesministerium für Verkehr , Innovation und Technologie, https://nachhaltigwirtschaften.at/resources/nw_pdf/201713-marktentwicklung-2016.pdf

6. BIOENERGY2020+ GmbH (2017): http://demoplants21.bioenergy2020.eu/projects/displaymap/EGpJO2

7. BMLFUW – Bundesministerium für Land- und Forstwirtschaft (2011): Richtlinie für den sachgerechten Einsatz von Pflanzenaschen zur Verwertung auf land- und forstwirtschaftlich genutzten Flächen.

8. Bradburn, K. 2014. CANBIO report on the status of bioenergy in Canada. Available from: http://www.fpac.ca/wp-content/uploads/2014_CanBio_Report.pdf [Accessed 22 July 2016].

9. BUWAL – Bundesamt für Umwelt, Wald und Landschaft (2005): Entsorgung von Abfällen in Zementwerken. Richtlinie. 2. Auflage, Okt. 2005. Hinweis: Anhang 1 „Positivliste“ datiert vom Mai 2007. Hrsg.: Bundesamt für Umwelt, Wald und Landschaft, Schweiz.

10. Canadian Electricity Association. 2014. Vision 2050: The future of Canada’s electricity system. Available from: http://www.electricity.ca/media/Vision2050/Vision2050.pdf [Accessed 15 May 2017].

11. CBS, 2017 www.cbs.nl .

12. Coote, D.C. E. Thiffault and M. Brown. 2016. Constraints and success factors for woody biomass energy systems in two countries with minimal bioenergy sectors. *In* E. Thiffault, G. Berndes, M. Junginger, J.N. Saddler and C.T. Smith (eds.). Mobilisation of forest bioenergy in the boreal and temperate biomes: challenges, opportunities and case studies. pp. 166-189. Academic Press, London, UK.

13. Elliott, A. and T. Mahmood. 2006. Beneficial uses of pulp and paper power boiler ash residues. TAPPI Journal 5: 9-16.

14. Elliott, A. and T. Mahmood. 2015. Generation and management of solid residues by Canadian pulp and paper mills in 2013. Confidential report prepared for FPInnovations.

15. Emilsson, S. 2006. International handbook: From extraction of forest fuels to ash recycling. Available from: http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=home.showFile&r

ep=file&fil=Recash_International_Handbook_Final2006_EN.pdf [Accessed 24 March 2017]

16. FIPER, 2015 (Italian Producer of Renewable Energy Federation, www.fiper.it)

17. G. Dinwoodie, Land Reclamation Specialist - Alberta Environment and Parks, Land Policy Branch, personal communication, September 2016

18. Government of Canada. 2016. The Government of Canada accelerates investments in clean electricity. Available from: http://news.gc.ca/web/article-en.do?nid=1157989 [Accessed 15 May 2017]

19. Government of Québec. 2016. Québec residual materials management policy under the Environment Quality Act. Available from: http://legisQuébec.gouv.qc.ca/en/ShowDoc/cr/Q-2,%20r.%2035.1 [Accessed 22 July 2016]

20. Griffin, B., and J. Nyboer. 2016. Renewable Energy in Canada 2015. Canadian Industrial Energy End-use Data and Analysis Centre. Simon Fraser University, Burnaby, B.C. Available from: http://www2.cieedac.sfu.ca/media/publications/Renewable_Energy_Report_2016_-_Final.pdf [Accessed 29 August 2016].

21. GSE – Rapporto Statistico Fonti Rinnovabili 2015

22. GSE, 2015 ("Incentivazione delle fonti rinnovabili Bollettino aggiornato al 31 dicembre 2015", http://www.gse.it/it/Dati%20e%20Bilanci/bollettino%20infomativo%20sull%20energia%20da%20fonti%20rinnovabili/Pagine/default.aspx)

23. Hannam, K.D., C. Deschamps, M. Kwiaton, L. Venier and P.W. Hazlett. 2016. Regulations and guidelines for the use of wood ash as a soil amendment in Canadian forests. Information report GLC-X-17. Available from: http://cfs.nrcan.gc.ca/publications?id=37781 [Accessed 22 March 2017]

24. Hannam, K.D., L. Venier, E. Hope, D. McKenney, D. Allen and P.W. Hazlett. 2017. Ashnet: Facilitating the use of wood ash as a forest soil amendment in Canada. Forestry Chronicle 93: 17-20. Available from: http://pubs.cif-ifc.org/doi/abs/10.5558/tfc2017-006 [Accessed 22 March 2017].

25. Hébert, M. 2015. Guide sur le recyclage des matières résiduelles fertilisantes: Critères de référence et norms réglementaires – Edition 2015. Available from: http://www.mddelcc.gouv.qc.ca/matieres/mat_res/fertilisantes/critere/guide-mrf.pdf [Accessed 22 July 2016]

26. Hébert, M. and B. Breton. 2008. Recyclage agricole des cendres de bois au Québec – État de la situation, impacts et bonnes pratiques agro-environnementales. Agrosolutions 19: 18-33. Available from: https://www.irda.qc.ca/assets/documents/Publications/documents/hebert-breton-2008_article_recyclage_agricole_cendres.pdf [Accessed 22 March 2016].

27. Hope, E.S., D.W. McKenney, D.J. Allen and J.H. Pedlar. A cost analysis of bioenergy-generated ash disposal options in Canada. Canadian Journal of Forest Research. *In press.*

28. http://www.energiaskor.se/remissvar.html

29. http://www.miljomal.se/sv/Miljomalen/

30. INGERSLEV, M.; SKOV, S.; SEVEL, L. & PEDERSEN, L.B. (2011): Element budgets of forest biomass combustion and ash fertilization – A Danish case study. Biomass and Bioenergy 35:7: 2697–2704.

31. INTERNATIONAL ENERGY AGENCY Statistics: http://www.iea.org/stats/WebGraphs/AUSTRIA5.pdf

32. ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale) data, 2014

33. LATVA-SOMPPI, J.; MOISIO, M.; KAUPPINEN, E.I.; VALMARI, T.; AHONEN, P.; TAPPER, U. & KESKINEN, J. (1998): Ash formation during fluidized-bed incineration of paper mill waste sludge. J. Aerosol Sci. Vol. 29 No. 4: 461–480.

34. LP Consulting. 2013. Available from: http://nsfa-fane.ca/wp-content/uploads/2012/10/2013-Nutrient-Management-Newsletter.pdf [Accessed 26 September 2016]

35. MacEachern, D.P. 2012. An assessment of wood ash on perennial forage stands. Available from: https://dalspace.library.dal.ca/xmlui/bitstream/handle/10222/15827/MacEachern,Daniel,MSc,Agro,November2012.pdf?sequence=1&isAllowed=y [Accessed 26 September 2016]

36. Madrali 2016, Canadian Bioheat Survey, Biocleantech Conf November 2016, Ottawa, ON, http://www.biocleantech.ca/presentations/madrali.pdf

37. MAUSCHITZ, G. (2014): Emissionen aus Anlagen der österreichischen Zementindustrie. Berichtsjahr 2013. Erstellt vom Institut für Verfahrenstechnik, Umwelttechnik und Technische Biowissenschaften, TU Wien. Hrsg.: Vereinigung der Österreichischen Zementindustrie, VÖZ.

38. Ministry of Agriculture, 2017

39. National Energy Board of Canada. 2016. Canada's Renewable Power Landscape. Available from: https://www.neb-one.gc.ca/nrg/sttstc/lctrct/rprt/2016cndrnwblpwr/2016cndrnwblpwr-eng.pdf [Accessed 20 March 2017].

40. National Energy Board of Canada. 2017. Market Snapshot: Canada's power generation: switching from coal to natural gas. Available from: https://www.neb-one.gc.ca/nrg/ntgrtd/mrkt/snpsht/2017/04-02cndpwrgnrtn-eng.html [Accessed 15 May 2017].

41. NEN, 2012. EN 450-1: Fly ash for concrete.

42. Nishio, G. 2016. Forest biomass ash production in British Columbia. Confidential report prepared for FPInnovations.

43. Nishio, G. and T. Ersson. 2016a. Ash and biosolids spreading trial. FPIPRODUCT-173-657. Available from: https://fpinnovations.ca/Extranet/Pages/AssetDetails.aspx?item=/Extranet/Assets/ResearchReportsFO/TR2016N28.pdf#.WNQT9BjMz-Y [Accessed 23 March 2017].

44. Nishio, G. and T. Ersson. 2016b. Spreading wood ash on forest land in Canada: An introduction. Technical Report no. 31. Available from: https://fpinnovations.ca/Extranet/Pages/AssetDetails.aspx?item=/Extranet/Assets/ResearchReportsFO/TR2016N31.pdf#.WNQVIhjMz-Y [Accessed 23 March 2017].

45. NMI (Nutrients Management Institute), 2018. Recovery possibilities of wood ashes, utilization modes (in Dutch, draft version)

46. Nova Scotia Environmental Farm Plan. 2016. Available from: http://www.nsfa-fane.ca/efp/soil-amendments/ [accessed 28 June 2016}

47. Nyboer, J., and N. Melton. 2015. Renewable Energy in Canada 2014. Canadian Industrial Energy End-use Data and Analysis Centre. Simon Fraser University, Burnaby, B.C. Available from: http://www2.cieedac.sfu.ca/media/publications/Renewable_Energy_Report_Final-1.pdf [Accessed 4 October 2016].

48. Nyboer, J., N. Melton, and S. Goldberg. 2014. Renewable Energy in Canada 2013. Canadian Industrial Energy End-use Data and Analysis Centre. Simon Fraser University, Burnaby, B.C. Available from:http://www2.cieedac.sfu.ca/media/publications/Renewables_Report_Final.pdf [Accessed 4 October 2016].

49. OBERNBERGER, I. & SUPANCIC, K. (2009): Possibilities of ash utilisation from biomass combustion plants. 17th European Biomass Conf. & Exhibition, Hamburg. Editor: ETA-Renewable Energies, IT

50. Ontario Power Generation (OPG). 2015. From coal to biomass: Generating a sustainable future. Available from: http://www.opg.com/about/environment/documents/opgbiomassconversion.pdf [Accessed 22 March 2017]

51. ÖSTERREICHISCHER BIOMASSEVERBAND (2017): Basisdaten Bioenergie 2017

52. Pitman, R.M. 2006. Wood ash use in forestry – a review of the environmental impacts. Forestry 79: 563-588.

53. Press release, Svenska EnergiAskor, http://www.energiaskor.se/pdf-dokument/PRESSMEDDELANDE1%20statistik.pdf

54. RWE, 2017. http://www.rwe.com/web/cms/nl/3342214/rwe-generation-se/brandstoffen/overzicht-locaties/nederland

55. SIMERI, http://www.gse.it/it/Statistiche/Simeri/Pagine/default.aspx (in Italian)

56. Skogsstyrelsen, http://www.energiaskor.se/PM_aska%20till%20skog%20och%20mark2.html

57. Skogsstyrelsen. 2008. Recommendations for extraction of harvesting residues and ash recycling. Available from: http://www.skogsstyrelsen.se/Global/PUBLIKATIONER/InEnglish/guidelines.pdf [Accessed: 24 March 2017]

58. STETTNER, U. & ZORMAIER, F. (2010): Verwertung und Beseitigung von Holzaschen. LWF aktuell 74/2010. Hrsg.: Bayrisches Landesamt für Umweltschutz.

59. UMWELTBUNDESAMT (2016): Biomasse-Ascheströme in Österreich

60. World Bioenergy Association, 2017. Global Biomass Statistics 2017

61. World Energy Council, 2016. World Energy Resources 2016

62. 2009/28/EC: DIRECTIVE 2009/28/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC

63. FNR: Fachagentur nachwachsende Rohstoffe (agency for renewable raw materials); https://bioenergie.fnr.de/bioenergie/biomasse/definition/

64. Waste Wood Reguation: Verordnung über Anforderungen an die Verwertung und Beseitigung von Altholz (Altholzverordnung – AltholzV – 2002/2017) [Regulation on requirement for utilisation and disposal of waste wood]

65. EEG – Rewable Energy Act: Gesetz für den Ausbau erneuerbarer Energien (Erneuerbare-Energien-Gesetz - EEG 2000/2017) [Act on the increase use of renewables energies]

66. BBE – Bundesverband Bioenergy: Strom (Federal Association Bioenergy: Power) https://www.bioenergie.de/themen/strom

67. Umweltbundesamt: Strom aus erneuerbaren Energien, Biomasse; (Federal Environmental Agency: Power from renewables, biomass); https://www.umweltbundesamt.de/themen/klima-energie/erneuerbare-energien/erneuerbare-energien-in-zahlen#strom

68. AGEE-Stat: Arbeitsgruppe Erneuerbare Energien-Statistik (Working group on renewable energy statistics), https://www.erneuerbare-energien.de/EE/Navigation/DE/Service/Erneuerbare_Energien in_Zahlen /Arbeitsgruppe/arbeitsgruppe_ee.html

69. Umweltbundesamt (UBA): Anlagenbestand in Deutschland [Federal Environmental Agency: plants in Germany], https://www.umweltbundesamt.de/themen/wirtschaft-konsum/industriebranchen/feue-rungsanlagen

70. FNR – Fachagentur Nachwachsende Rohstoffe: Strohheizung Gülzow [Agency for renewable raw materials: straw heating Gülzow], https://bioenergie.fnr.de/bioenergie/strohheizung-guelzow/

71. Bioenergiekraftwerk Emsland [bioenergy power station Emsland], http://www.bioenergie-emsland.de/

72. Umweltbundesamt: Kleine und mittlere Feuerungsanlagen [Federal Environmental Agency: small and medium sized combustion plants] https://www.umweltbundesamt.de/themen/wirtschaft-konsum/ industriebranchen/feuerungsanlagen/kleine-mittlere-feuerungsanlagen

73. Agentur für erneuerbare Energien [Agency for renewable energies]: Anzahl Holzheizkraftwerke [Number of wood-fired heating plants], https://www.foederal-erneuerbar.de/landesinfo/bundesland /BY/kategorie/bioenergie/#goto_191

74. Döring, P., Weimar, H., Mantau, U.: Einsatz von Holz in Biomassegrossfeuerungsanlagen 2016, in ROHSTOFFMONITORING HOLZ - Mengenmäßige Erfassung und Bilanzierung der Holzverwendung in Deutschland, S. 102 ff, [use of wood in large biomass combustion plants 2016, in raw materials monitoring wood – compilation of balancing of the wood use in Germany], https://mediathek.fnr.de/broschuren/sammlungen/schriftenreihe-nr/rohstoffmonitoring-holz-mengenmaessige-erfassung-und-bilanzierung-der-holzverwendung-in-deutschland.html

75. Döring, P., Glasenapp, S., Weimar, H., Mantau, U.: Die energetische Nutzung von Holz in Biomassefeuerungsanlagen unter 1 MW in Nichthaushalten in 2016, in ROHSTOFFMONITORING HOLZ - Mengenmäßige Erfassung und Bilanzierung der Holzverwendung in Deutschland, S. 122 ff, [The energetical use of wood in biomass combustion plants < 1 MW except in households in 2016, in raw materials monitoring wood – compilation of balancing of the wood use in Germany], https://mediathek.fnr.de/broschuren/sammlungen/schriftenreihe-nr/rohstoffmonitoring-holz-mengenmaessige-erfassung-und-bilanzierung-der-holzverwendung-in-deutschland.html

76. Statista: **Verwertung von Altholz in Deutschland nach Verwertungsweg im Jahr 2009 [Utilisation of waste wood in Germany by utilisation paths in 2009],** https://de.statista.com/statistik/daten/studie/ **168690/umfrage/verwertungswege-von-altholz-in-deutschland/**

77. **Verordnung über Deponien und Langzeitlager (Deponieverordnung – DepV), 04.2009 [Decree about disposal sites and long term storage site]**

78. Verordnung über das Inverkehrbringen von Düngemitteln, Bodenhilfsstoffen, Kultursubstraten und Pflanzenhilfsmittel (Düngemittelverordnung – DüMV); 2012 [Decree about the marketing of fertilisers, substrates and plant auxiliary means]

79. Merkblatt: Verwertung und Beseitigung von Holzaschen, Bayerisches Landesamt für Umwelt, 2009
[guidance on the use and disposal of wood ashe]

80. Wilpert von, K., Harmann, P., Schäffer, J.: Qualitätskontrolle bei einem Konzept für Holzasche Recycling für Wäder [Quality control in wood ash re-cycling concept for forests], VGB PowerTech 04.2016

81. Bundesgütegemeinschaft Holzaschen e.V. [Federal Quality Association for Wood Ash] https://www.holzaschen.de/

82. Verordnung über den Versatz von Versatz von Abfällen unter Tage (Versatzverordnung – VersatzV) [Decree about the use of waste for underground mine fill]; 07.2002Spliethoff, H.,

83. Fendt, S., Spliethoff, H., Frandsen, F.: Biofficiency – joint research on fuel, process and ash qualities, VGB Workshop Biomass Ash, May 2017

IEA Bioenergy

Further Information

IEA Bioenergy Website
www.ieabioenergy.com

Contact us:
www.ieabioenergy.com/contact-us/