# Biomass ash fertilisation sustains the bio energy cycle

Jarno Romppanen

## Der Bio-Energie-Kreislauf wird durch Biomasseaschedüngung aufrecht erhalten

*Biomasse wird als erneuerbare Energiequelle vermarktet. Durch die kontinuierliche, jährliche Ernte der Biomasse verschlechtert sich die Bodenbeschaffenheit und als Folge verlangsamt sich das Wachstum, was wiederum zu kontinuierlich sinkenden Erträgen führt. Reine Biomasse-Brennstoffe sind voller nützlicher, natürlicher Nährstoffe. Auch durch den Verbrennungsprozess werden diese Nährstoffe nicht entfernt, sondern verbleiben in den wertvollen Aschen der Biomasse, die auch einen hohen Gehalt an Kalzium enthalten, der die Auswirkungen von saurem Regen neutralisieren kann.*

*Als wertvolles Nebenprodukt hat Biomasse-Asche ein enormes Potenzial zur Vervollständigung der Produktionskette erneuerbarer Energie.*

*Reaktive Flugasche muss entsprechend behandelt werden, um Auswirkungen auf Bäume und Unterholz zu vermeiden. Die Alterung von Biomasse-Flugasche kann durch die Selbsterhärtung oder Granulationstechnik bewerkstelligt werden. Tecwill Granulators Oy hat Granulations-Stationen entwickelt, die aus reaktiver Flugasche granulierten und natürlichen Dünger erzeugen. Die Granulationstechnik ist ein äußerst effizientes und ökonomisches Verfahren zur Behandlung von Flugasche.*

*Die Ascheverwendung kann mit den gleichen Beteiligten verwirklicht werden, die auch schon bei der Biobrennstoffversorgung zusammenarbeiten. Die Waldbesitzer werden dadurch einen größeren Ertrag an Biomasse erzielen. Die Energieerzeuger haben eine weitere Möglichkeit den Anforderungen und Regelungen zur Nachhaltigkeit nachzukommen.*

*Wenn sich alle beteiligten Parteien einer nachhaltigen Produktion verpflichten, so besteht für die Nutzung von Biomasseasche als Düngemittel keine wirtschaftliche Barriere.*

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## Introduction

Sustainable and environmentally-friendly energy production and energy self-sufficiency are commonly used terms in the international energy debate. The European Commission's 2020 targets (20 % less greenhouse emissions, 20 % of energy from renewables and 20 % increase in energy efficiency) and changed geopolitical situations have generated demand for increased local energy production in Europe. The biomass industry is expected to contribute over half to this overall EU target, roughly 12 %, through the applications of biomass in transport, electricity and in heating. [1] Photovoltaic and wind energy are globally most popular renewable energy sources. But also biomass combustion for energy and heat is rising as it can generate a stable base, non-varying energy source and peak load electricity, unlike photovoltaic and wind energy. Most of the biggest cities and villages already use biomass-fired combined heat and power plants (CHP) in Finland, Sweden and Germany. There are several big convergence projects going on in Denmark, where older coal-fired power plants are converted into bio fuels. The biggest bio CHP power plant in Europe is about to be ready in Värta, Stockholm, Sweden [2]. There will be more biomass-fired power plants all around European cities. Austria, Germany, the UK, Denmark, Finland and Sweden are leading this process, mostly producing bio-electricity from wood residues in cogeneration plants [1].

The European industry increasingly prefers combined heat and power plant because of high process-related thermal requirements, which are not allowed to be subject to daily or seasonal weather-related fluctuations [3]. Biomass fuels are available almost everywhere and these fuels are local and easily available all year round.

Biomass-fired combustion plants are marketed as renewable energy sources. Sustainable produced biofuels are considered renewable. The growth of biomass will bind carbon dioxide and compensate exhausts. Biomass production areas may be harvested year after year. When biomass is harvested continuously from the production area, the soil of that area will degrade slowly which will slow down the growth of biomass. Another growth limiting factor is acid rain fall. Emission causes acid rain around highly populated areas. They change the natural pH level of soil and decreases activities of microorganisms into the soil.

Biomass combustion plants generate an extensive variety of ashes which are generally listed as waste according to EU Regulations and Directives. Depending on the fuels used (green wood to waste wood), ashes may vary from nutrient-rich or toxically-hazardous waste and something between these two extremes. Biomass ashes are commonly used in infrastructure building applications, in mine backfill and as fertiliser or are disposed off at landfills. For a decision regarding utilisation or disposal, the ashes should be analysed and sorted out based on the source of fuels and the chemical composition of ashes.

Clean biomass like chipped wood, forest residues, bark, herbaceous energy crops are full of useful nutrients like phosphorus (P) and potassium (K). The combustion process does not remove these valuable nutrients which remain inside biomass ash. Biomass ashes also contain a high content of calcium, which may neutralise the adverse symptoms of acid rain.

There is a huge potential in valuable biomass ashes which can complete renewable energy production. Ashes can sustain local biomass production and secure local sustainable energy production for the future generations and are therefore closing a bio energy cycle.

## Biomass ash as fertiliser – History in Nordic countries

Nutrient deficiency limits the growth of trees remarkably and causes declining productivity in forests. Vital nutrients for forest growth are nitrogen, phosphorus and potassium (N, P, K). If forest areas are harvested regularly, each biomass harvesting cycle will deplete the amount of available nutrients inside the soil of the forest area. Persistent and continuously increasing acid rain falls change the pH level of forest soils, which causes even more productivity losses in forest areas.

Ashes from biomass combustion plants and biomass ash fertilisation have been studied widely in Finland and Sweden. In Finland, forest ash fertilising has been studied for more than 80 years now. The first experiments were carried out in the late 1930s by the Finnish Forest Research Institute [4].


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*Fig. 1. Effect of biomass ash fertilising to the needles. Left pine, right bruce, there are branches without fertilisation (left) and with fertilisation (right) in the both pictures [5].*

Studies covered different forest soils, ash qualities, tree growth, impact to forest berries, mushrooms, water systems and greenhouse gases. Solubility, nutrient leaching and granulation effects of the ash fertiliser have been studied, too. [4]

The results of these first fertilisation trials on drained peat lands showed that the use of biomass ash increases tree growth and improves the natural stand regeneration. The early studies also demonstrated that ash fertilisation accelerated the activity of micro-organisms in the surface peat. Later studies have supported these findings and confirmed that the effects are long-lasting [9].

Wood-based biomass fuels are commonly used in local district heating power plants in Finland and Sweden. Both countries have one of the Europe's biggest forest areas, and it produces new biomass continuously. Finland and Sweden are forerunners in ash recycling and use of a variety of different recycling applications, not only forest fertilisation.

Most of nutrients are inside the bark and other forest residues, like branches, crowns, leaves and needles. The ashes from a combination of these tree parts would be the best for a fertiliser. There are just few power plants in Europe, which burn just these bio fuels. Alkaline metals, potassium and sodium from biofuels cause slag formation and hot corrosion inside the boilers. Sulphur-containing fuels like peat or separate sulphur feeding is normally used to prevent these symptoms. The chemical composition of ashes varies largely due to fuel quality, fuel mix and boiler technology.

The biomass combustion process produces different types of ashes, like bottom ash and fly ashes. Bottom ash is extracted from the bottom of the boiler. Fly ash is separated from flue gases by different kind of filters and separators. Each fly ash has to be studied separately to determine the suitability of the ash for fertilisation. With the implementation of the EU Waste Directives each European country has adjusted unique waste, recycling, fertilisation and environmental legislations, which set the framework for ash recycling and reuse, like forest fertilisation. Biomass ashes are allowed to be used as forest fertiliser in Finland and Sweden.

## Biomass ash – Impact of fuel and process on composition

Most of the nutrients are inside fine-grained fly ash. Circulation fluidised bed (CFB) and bubbling (stationary) fluidised bed (BFB) boilers are used in CHP power plants. The biggest ash fractions are filter and cyclone ashes, so-called fly ashes. There is also some reactive calcium inside biomass fly ashes. Biomass fly ash has a good neutralising capacity (pH 10 to 13). There are some heavy metals as cadmium (Cd) and arsenic (As) concentrated in the fly ash as well. These heavy metals come originally from used bio fuels. Each tree contains also heavy metals naturally due to growing on specific ground. If fly ash will be treated accordingly and ash fertiliser spreading protocols are followed, there is no risk for heavy metal leaching to forest soils, surface waters or contamination of forest berries and mushrooms or hazarding wildlife or hikers. Finland and Sweden have similar ash spreading regulations and instructions. Long-term and field tests still ongoing in Finland and Sweden have proven ash fertilising to be safe and environmentally friendly recycling option.

Compared to fly ash, bottom ash does not have comparable fertilising properties. Bottom ash contains normally boiler sand and incombustible materials like stones, slag and metal pieces from used bio fuels. Bottom ash may be used appropriately in infrastructure building applications.

Ash forest fertiliser suits best for nitrogen-rich peat soil forest areas, which have deficiency of phosphorus and potassium and the soil is highly acidic (pH 4 to 5). Deficiency and correction of soil pH may be recognised in the forest appearance. Tree needles change colour from yellow to dark green, while their size increases after three to four years from ash fertilising (Figure 1).

Nutrient levels of peat soil forests have been found to remain good even from twenty to fifty years after ash fertilisation. Along with decreased acidity, the activities of microorganisms become more efficient and they start to utilise nutrients from forest soil. Then microorganisms produce more nutrients for undergrowth and trees. In nitrogen-rich forest areas the increase in tree growth is approximately 2 to 6 $m^3$/ha/a and on nitrogen-poor sites 1 to 3 $m^3$/ha/a during one rotation (Figure 2).

Suitable ash fertilisation amount depends on the soils nutrient contents. Normally 3 to 5 t/ha is a suitable amount to meet Finnish forest fertilisation recommendations, phosphorus 40 to 50 kg/ha and potassium 80 to 100 kg/ha. Normally woods will be fertilised with ash after thinning of young forest and ditching [4]. The ash fertilising does not generate such a huge and instant impact in mineral soil. Deficiency of nitrogen usually limits the growth of trees on mineral soil areas. Ash fertilisers do not contain nitrogen as nitrogen is released


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*Fig. 2. Control peatland forest area not fertilised (left). Ash fertilised peatland forest area (right). Biomass ash fertilising has been done 15 years ago. Located in Pelso peatland forest in Vaala [5].*

from the boiler. However, ash fertilising can compensate nutrient losses of bio-fuel intensive harvesting and neutralise the pH of the soil. Ash fertilising can maintain the fertility of mineral soil forest areas. The Swedish board of forestry has published guidelines on how to compensate nutrients, which are taken away along forest residue harvesting and clear cut. Ash fertilising is also recommended to compensate soil acidification. In the southern part of Sweden, chemical forest fertilisers are forbidden and only ash forest fertilisation is allowed [6].

Missing nitrogen can be combined into ash fertiliser as a separate fertiliser. Combination of two separate fertilisers would generate more growth on mineral soil forest areas. Other industrial by-products may also be used as a source of nitrogen. Currently in Finland and Sweden there are several ongoing studies on how to combine nutrient rich industrial by-products into forest fertilisers.

## Reactive fly ash into ash fertiliser

Reactive fly ash (mostly consisting of high amount of calcium) has to be treated accordingly to avoid burning of vegetation (by reactive lime) and dusting impacts to trees and undergrowth. Reactive fly ash should be stabilised with water. This stabilisation process is also called aging. Fly ash needs proper amount of water to be added and then hardening reaction will start. The calcium oxide in biomass fly ash change into calcium carbonate due to the reaction with water and carbon dioxide. Similar carbonation process is known from hardened concrete structures. Heavy metals in fly ash remain in very slowly dissolving form due to high alkalinity of ash. Aging of fly ash does not change the pH.

Biomass fly ash can be aged with self-hardening or granulation techniques. The self-hardening treatment method is manual and a labour-intensive method, which includes many different, time consuming phases like moisturisation, transportation, long period stack storing, crushing, screening and storing.

Ash granulation is the most effective ash stabilisation method currently in use. Ash constituents may be "enhanced" during the granulation process with additive nutrients (Figure 3, [4]).

Tecwill Granulators Oy has developed bio ash granulation stations, processing reactive fly ash into granulated, natural fertiliser. The production process is a fully industrial, manageable process. Fly ash will be stabilised, aged and granulated in a continuing production process. The industrial production process of granulation plant gives opportunities to combine several industrial by-products, like biogas production's reject waters, as one recycled natural fertiliser or create tailor-made natural fertiliser regarding depletion of nutrients of specific forest area. The amount of water used may be optimised to minimum and desired ageing of bio fly ash is still reached. Excessive water in granules causes only extra transportation and spreading costs. The size of the granules is regulated with the production parameters of the process. Fresh ash granules continue hardening and drying process also within a few weeks after the granulation. Afterwards, the ash fertilising granules are ready for sales, transportation and spreading. They can be transported loose or big bagged.

The granulation system is an efficient and economical way to process fly ashes. The granulation plant can be located next to a power plant (Figure 4) or on a separate production area between power plant and biomass production area.

## Biomass ash fertilising sustains bio energy cycle

As new biomass combustion plants (CHP) are being built, better biomass ash is produced. The EU Waste Directive with integrated waste hierarchy obligates to recycle and reuse wastes which may also be considered industrial by-products. The member states have set national waste taxes to speed up recycling and reuse of industrial by-products. Finland and Sweden have set waste tax to 55 € per each unused tonne of waste. Finland raised its waste tax to 70 € per tonne at the beginning of 2016.

As energy consumers are more aware of sustainability and environmentally friendly production methods and consumers are also willing to pay more for sustainably produced energy, ash recycling in forests has been established. This leads to main-

*Fig. 3. Biomass ash granulation.*


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*Fig. 4. Biomass ash granulation plant next to the biomass CHP plant in Rovaniemi, Finland.*

taining the nutrient balance of bio fuel production areas and securing future biomass production. With that the total bio energy and fuel cycle is complete, not shorthanded. The energy companies may support sustainable development and the recycling economy of local communities. Less waste is dumped in landfills. The ash fertilising solution is also a long-term recycling solution, which creates stability and predictability in business environment. Disposal cost and waste taxes of ash may be turned into revenues from ash fertiliser sales.

Biomass energy has a giant socioeconomic impact. The increased use of solid biomass (+8 % in the EU in 2010) underlines its crucial role in creating turnover in the EU member states. Investments are made for the installation of CHP plants, the accompanying equipment and the sale of biomass boilers, furnaces or stoves for individual households. The forest sector is a major employer [1].

Ash recycling, including ash granulation, may be organised with the same actors of the already existing biofuel supply chain. Forest or field owners sell bio fuels to energy companies and buy ash fertilisers to enhance forest growth. Biofuels are transported from production areas (forests and fields) to the fuel terminals of power plants. The same trucks may transport granulated ash fertiliser back to forest areas as a return cargo. Biofuel harvesting companies could spread the granulated ash fertiliser after having harvested biomass. Harvesting companies could expand services to fertilising services. Commercial spreading equipment is available, which can be installed on top of normal forest forwarders. All necessary equipment is already developed (Figure 5).

Granulated ash can also be spread by helicopters. Helicopter spreading is more expensive, but it is more efficient, faster and enables access to rough and wet forest areas. Helicopter spreading does not cause any damage to undergrowth and root of trees like ground spreading. Heavy ground spreading forest forwarders need more solid ground to operate.

The forest owners will have more biomass in the future. Ash fertilising on peat soil forest areas is one of the most profitable forestry investment. Ash forest fertilising increases forest growth by 4 $m^3$/ha/a. The value of the additional growth is the same as with harvested timber (25 €/$m^3$). Considering an effective yield time of ash fertilisation of 40 years, the total sale revenues from additional forest growth can be estimated to 4,000 €/ha. The interest rate of the ash forest fertilising investment is 10 to 20 % [8].

There are local markets for recycled natural ash fertilising. Biomass ash fertilisers can compete against commercial fertilisers with price and overwhelming properties. Biomass ash fertilisers are locally produced unlike commercial options. Fertilising impact with biomass ash lasts decades longer than chemical competitors. The challenge is just to convince forest owners and energy companies about the benefits of ash forest fertilisation. Energy companies have all possibilities to guide sustainable biofuel production with sustainable requirements and policies. If energy users, energy companies and forest owner are committed to

*Fig. 5. Granulated ash fertiliser ground spreading in Loue during spring winter 2015, Finland [7].*


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sustainability, there is no economical barrier for ash fertilising.

## Summary/result

The more biomass combustion CHP plants are built, the more valuable biomass ash is being produced. There is a continuously growing market for renewable energy. Photovoltaic and wind power cannot produce enough energy. There will be fluctuation and biomass combustion can supply heat and power efficiently without interruption. Combined heat and power production is an economical and energy-efficient way to utilise all potentials of biomass fuels. More district heating systems should be built inside cities and villages. District heating systems can replace coal and natural gas usage in heating of residential buildings.

Biomass-fired combustion plants are marketed as renewable energy sources. Sustainably produced biofuels are renewable. Forest or agro crops will grow again after a while from harvesting. The growth of biomass will bind carbon dioxide and compensate carbon dioxide exhausts. The same biomass production areas can be harvested again after years. If biomass will be harvested intensively and continuously from the same production area, the soil of production are will degrade slowly. Degradation of soil will slow down growth of biomass.

Biomass ashes have valuable properties like nutrients and neutralisation ability. Biomass ashes can be recycled back to biomass production areas. Nutrients will remain in the cycle and pH level of soils will stay on natural level. The awareness of environmentally friendly, sustainable energy production is arising. Consumers are willing to pay for sustainably produced energy. It would be useful to develop a EU Directive for biomass ash recycling as basis for member states to adapt their individual guidelines and legislation to increase ash recycling. Many European countries do not have a distinct legislation and guidelines to recycle industrial by-products.

Stakeholders and technologies for increased use of biomass ash as forest fertiliser are ready. The biomass ash sustainable recycle only needs to be organised from the existing biofuel supply chain. The recycling solution has to be sustainable, i.e. environmentally friendly, socially acceptable and economically profitable. Biomass ash fertilising is indeed as sustainable recycling option. Now it is time to create the real application of the circular economy.

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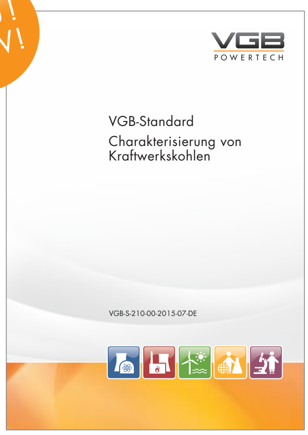


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