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Biochar-Urban Forestry Strategy

FOR THE CITY OF STOCKHOLM, SWEDEN

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1 Feedstock availability

Biomass with a high content of lignin, cellulose and hemicellulose is suitable feedstock for biochar production as it generates a biochar with an anticipated set of qualities and characteristics. Char from biosolids tends to be less stable as a carbon sink and has considerably differentiating properties (McIntosh & Hunt, n d). European Biochar Certificate (EBC) has a list of biomass feedstock approved for use in producing biochar (EBC, n d). Feedstock should be untreated (in terms of e.g. paint or impregnation – nails can be separated) and classified as a waste or as a residual material (EBC, 2012).

Biosolids are currently not included in EBC's positive list, however sludge and food waste have been included in Table 1 and 2 below, showing the potential urban feedstock availability, since trials with pyrolyzed sludge as well as food waste is being conducted and the product is sometimes referred to as biochar in the literature.

New fertilizer regulations enter into force in June 2022 within EU, where biochar is one component in the concept "pyrolysis and gasification material" (EUR-Lex, 2019).

This report is based on the current state of knowledge as well as on the City of Stockholm's needs and conditions for biochar production and use, rather than for the Stockholm greater area.

1.1 City of Stockholm

Table 1 describes and estimates the potential urban feedstock being produced and available in the City of Stockholm, suitable for biochar production.

Table 1. Describes the amount and origin of feedstock within the city of Stockholm that is suitable for biochar production.

Feedstock	Amount (tonnes/year)	Origin	Comment	Biochar potential (tonnes/year)
Garden waste, woody biomass	5 550 (Dahllöf, 2021)	Households	(Incl. Christmas trees.) Is being crushed today. Approx. 50% of total amount is suitable for biochar production. Moisture content approx. 40%	420
Urban tree residues, woody biomass	3 800 (Dahllöf, 2021)	Municipality; urban tree maintenance	(Street trees.) Is being chipped today: corresponds to a poor fraction of forest residues, why approx. 70% of total amount is suitable for biochar production. Moisture content approx. 40%	290
Park waste	400-700 (Dahllöf, 2021)	Biomass collected from park and other municipal green area maintenance	Mixed materials. Approx. 50% of total amount is suitable for biochar production. Moisture content approx. 40%	30-50
Wood pallets and wood packaging material	N.A.	Household, municipal activities, commercial waste	Handling of material is responsibility of producer (Lyckeborg, 2022)	N.A.
Demolition wood waste	19 887 (Community recycling center) (Lyckeborg, 2022)	Households and businesses	Heterogeneous & unclean material. Chipped for energy recovery today. Additional significant amounts are being handled by commercial disposal. Approx. 80% of total amounts is suitable for biochar production. Moisture content approx. 20%	3200
Solid digestate, from biosolids	77 600 (Dahllöf, 2021)	Henriksdals and Bromma treatment plants. Produced from anaerobic digestion of waste (such as sewage sludge)	21 728 dry matter t/y. 56 700 tonnes go to arable land, the rest is used for soil improvement, final disposal of landfill and incineration attempts. Approx. 100% of total amounts is suitable for biochar production. Moisture content approx. 72%	5500
Food waste	100 000 (Dahllöf, 2021)	Majority from households	25 000 tonnes are sorted out of household waste, the rest goes to waste incineration. Approx. 100% of total amounts is suitable for biochar production. Moisture content approx. 70%	7600

1.2 Sweden

Table 2 describes and estimates the potential urban feedstock being produced and available in Sweden for biochar production.

Table 2. Describes the amount and origin of feedstock in Sweden with potential for biochar production.

Feedstock	Amount (tonnes/year)	Comment	Biochar potential (tonnes/year)
Garden waste, woody biomass	439 000 (Avfall Sverige, 2022)	Moisture content approx. 40%. Approx. 50% of total amounts is suitable for biochar production.	33 000
Urban tree residues, woody biomass	N.A.	Moisture content approx. 40%. Approx. 50% of total amounts is suitable for biochar production.	N.A.
Park waste	N.A.	Moisture content approx. 40%. Approx. 50% of total amounts is suitable for biochar production.	N.A.
Wood pallets and wood packaging material	N.A.	N.A.	N.A.
Demolition wood waste (not impregnated wood)	538 000 (Avfall Sverige, 2022)	Moisture content approx. 20%. Approx. 80% of total amounts is suitable for biochar production.	87 000
Solid digestate, from biosolids	277 778 (Avfall Sverige, 2022)	Moisture content approx. 72%. Approx. 100% of total amounts is suitable for biochar production.	50 000
Food waste	425 551 (Avfall Sverige, 2022)	Moisture content approx. 70%. Approx. 100% of total amounts is suitable for biochar production.	32 000

2 Use potential

Biochar has a wide range of potential urban use application areas. This section demonstrates that by referring to previous and ongoing pilots and trials.

Table 3 and 4 lists application areas for biochar in urban public green areas; the recommended or tested amount of biochar for each application; the extent of each application area; as well as the accompanying projected benefits and the biochar use potential in cubic meters as well as tonnes (yearly in Table 3 and total amount in table 4) for each application.

Table 3. Lists application areas for biochar in the City of Stockholm as well as appropriate amounts of biochar, extent of each application area, projected benefits and yearly biochar use potential for each application.

Application area	Amount	Benefits*	Biochar potential (yearly)
Tree plantings in structural soil, Stockholm model (Stockholm stad, 2017)	**Per application**: 7-20 vol% biochar is sought. For practical reasons 7.5 vol% or 12.5 vol% is often used (Fransson, Gustafsson, Malmberg, & Paulsson, 2020) 15 m^3 soil/tree ≈ 2 m^3 biochar/tree (Alvem, 2022) **Yearly implementation**: approx. 700 trees/year (Alvem, 2022)	**Direct**: increased tree growth & higher drought resistance. Stormwater management. Pollutant immobilisation and less nutrient leaching. **Indirect**: increase in recreational values, biodiversity support, ecosystem services & carbon sequestration. Reduced urban heat island effect. Reduced risk of flooding by enabling local water storage/handling. Pollutant degradation, better water quality.	700 trees * 2 m^3 = **1 400 m^3 biochar (approx. 280 tonnes)**
Urban plant beds, perennials	**Per application**: 12.5 vol% biochar (Fransson, Gustafsson, Malmberg, & Paulsson, 2020) **Yearly implementation**: 2-5 ha with 40 cm depth (Alvem, 2022)	**Direct**: less nutrient leaching, less dependence on mineral fertilizers, higher drought resistance & better plant growth. **Indirect**: increased biodiversity support & recreational values. Less maintenance. Improved water quality in surrounding water bodies.	12.5 vol% * 2–5 ha*40 cm = **1 000–2 500 m^3 biochar (200–500 tonnes)**
Green areas (parks, football pitches, golf courses, etc.)	**Per application:** 5 vol% biochar in the 10 top cm of soil (Alvem, 2022) **Yearly implementation:** 5 ha of park are rebuilt/year (Alvem, 2022)	**Direct**: stronger root systems on grass increasing durability and grass quality. **Indirect**: prolongs the season played on natural grass. Reduces microplastic pollutants if replacing plastic fields. Increased aesthetic values.	5 vol% * top 10 cm * 5 ha = **250 m^3 biochar (approx. 50 tonnes)**

Application area	Amount	Benefits*	Biochar potential (yearly)
Peat substituent (in e.g. potting soil)	**Per application**: 10-33 vol% biochar has been shown to be able to substitute peat with sustained growth in salad (Fransson, Gustafsson, Malmberg, & Paulsson, 2020) **Yearly implementation**: approx. 700 "city pots"; 750-1 000 m^3 peat-based soil (Alvem, 2022)	**Direct**: reduced need for peat and liming. The biochar can compensate for the emissions following peat use. **Indirect**: reduced GHG-emissions from reduced use of peat.	10-33 vol% * 750 – 1 000 m^3 = **75-330 m^3 biochar (approx. 15-66 tonnes)**
Concrete	**Per application**: 15 M% of cement can be substituted with biochar (Bier, 2021) ≈ 2.25 M% biochar in concrete (with a compressive strength suitable for tree pit foundations) (Cementa, n d) **Yearly implementation:** 300 tree pit foundations and 40 000 m^2 of concrete floor slabs (for streets) (Alvem, 2022)	**Direct**: Improved: water absorption, strength and toughness, flexural strength (nano/micro particle size), hydration and accelerates in early strength, and improved impermeability. Reduced use of cement. Can make concrete lighter and/or stronger.	Approx. 12 kg biochar/tree pit foundation * 300 pcs = **3.6 tonnes**. + 2.25 M% biochar * 180 kg/m^2 concrete floor slabs (S:T Eriks, n d) * 40 000 m^2 **= 825 m^3 biochar (approx. 165 tonnes)**
Animal feed	**No estimate** of use potential has been made as there is currently no local market for this type of use. Note that there are requirements for the quality of the constituent materials as the biochar should meet the higher requirements EBC places on biochar for animal feed.	**Direct:** potential to improve animal health, feed efficiency and livestock housing climate, to reduce nutrient losses and greenhouse gas emissions (Schmidt, Hagemann, Draper, & Kammann, 2019). **Indirect:** potential to reduce antibiotic use. Biochar-manure is produced – a valuable organic fertilizer.	

**Not all benefits can be guaranteed but have been seen or reported to varying degrees in pilots and trials.*

Table 4. Lists application areas for biochar in the City of Stockholm as well as appropriate amounts of biochar, extent of each application area, projected benefits and <u>total</u> biochar use potential for each application.

Application area	Amount	Benefits*	Biochar potential (total)
Green roofs	**Per application**: 30 vol% biochar potential in green roof substrate (Cao, Farrell, Kristiansen, & Rayner, 2014). ≥80-100 mm substrate thickness is recommended (Catalano, Armano Laudicina, Badalucco, & Guarino, 2018) **Green roof area potential**: 1-5 m^2 per capita (over the past 5 years, Stockholm has expanded its green roof area, and is approaching other major European cities) (Grant & Gedge, 2019) (Malmberg, 2022)	**Direct**: less nutrient leaching, less dependence on mineral fertilizers, higher drought resistance & better plant growth. **Indirect**: increase in recreational values, biodiversity support & ecosystem services. Less maintenance. Reduced urban heat island effect. Natural insulation of building (temp. & noise).	30 vol% * 100 mm * (1-5 m^2 * 1 million citizens) = **30-150 000 m^3 biochar (approx. 6-30 000 tonnes)**
Tree plantings/urban forests, in vegetation area	**Per application**: 5 vol% biochar * top 10 cm – alternatively biochar air-lance injection approx. 40 L/tree (Fransson, Gustafsson, Malmberg, & Paulsson, 2020) **Urban forest within city limits:** 1 000 000 trees in total. 10% of which soil improvement can be done, i.e. 10 000 trees totally (1 000 trees/year) (Alvem, 2022)	**Direct**: increased tree growth & higher drought resistance. **Indirect**: increase in recreational values, biodiversity support, ecosystem services & carbon sequestration. Reduced urban heat island effect.	1 000 trees * 40 L biochar * 10 years = = **400 m^3 biochar (approx. 80 tonnes)**

**Not all benefits can be guaranteed but have been seen or reported to varying degrees in pilots and trials.*

2.1 Different biochar

The EBC lists limit values for, for example, PAHs and heavy metals in biochar based on the intended area of application (animal feed, agricultural land, urban use, materials, etc.) (EBC, n d). It is recommended to follow these guidelines.

Depending on how and from what the biochar has been produced it will attain different characteristics. This may make the biochar more suitable for some applications rather than others. Kind of feedstock and temperature are the main parameters causing the biochar to have different characteristics (Tomczyk, Sokolowska, & Boguta, 2020). See Table 5 for information on some of the main characteristics of biochar.

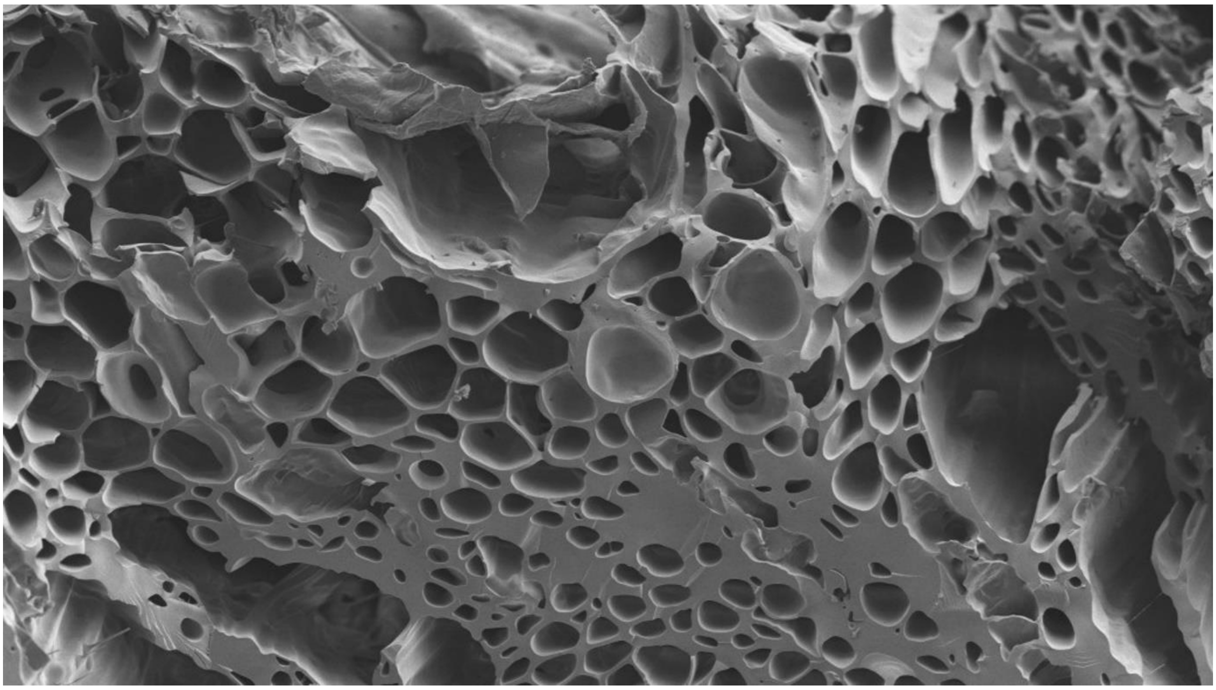

Table 5. Describes some of the main different characteristics depending on temperature and how it affects the suitability of the use of the biochar.

Characteristic	Causing parameter	Suitable use
High CEC (cation exchange capacity ≈ nutrient adsorbing capacity)	Lower prod. temp. tends to generate higher CEC, as well as feedstock such as manure and biosolids (Tomczyk, Sokolowska, & Boguta, 2020).	Can contribute to reduced nutrient leaching which makes the biochar suitable in most plant beds, especially in green roofs and rain gardens. Sandy soils tend to have poor nutrient holding capacity.
High ash content - often correlates to high pH	High prod. temp., some feedstock (such as bark and grain husk) as well as other materials (soil or inorganic materials) generates more ash (Fransson, Gustafsson, Malmberg, & Paulsson, 2020)	Biochar with high ash fraction and liming effect should be carefully used in urban meadows where it could disfavor meadow plants. Suitable for soil that needs minerals and/or liming. In Stockholm´s structure soils

Characteristic	Causing parameter	Suitable use
	(Tomczyk, Sokolowska, & Boguta, 2020).	too high ash content is not recommended since the stormwater might flush the ash nutrients to the recipient. The city's limits for biochar: 7.5% & park and garden waste-biochar: 20%.
High WHC (water holding capacity)	High prod. temp. enhances porosity which causes higher WHC, but it also causes higher aromaticity which can have hydrophobic effects (Batista, o.a., 2018). Smaller particle size can increase water retention (Tomczyk, Sokolowska, & Boguta, 2020).	Biochar can often enhance a substrates WHC, especially in sandy soils. This is a suitable characteristic in draft exposed and thin plant beds. In heavy and/or compacted soils it can reversely enhance the air content.
Fraction size	The size of ingoing feedstock, mechanic handling of the biochar and abiotic factors (e.g. ground frost).	For urban use, fraction size of biochar is usually 0-10 mm, sometimes 0-20 mm. (Large fraction size can make soil/substrate looser.)

2.2 Methods of biochar use

This section presents several recipes with biochar. Note that percent refers to percent by volume.

- **Structural soil, Stockholm model**:
    - Plant beds and perennials: 75 vol% macadam (4-8), 12.5 vol% biochar and 12.5 vol% compost (Fransson, Gustafsson, Malmberg, & Paulsson, 2020)
    - Trees: 85 vol% macadam (32-90), 7.5 vol% biochar and 7.5 vol% compost (Stockholm stad, 2017)
- **Bluegreengrey (BGG) systems**:
  BGG systems are developed for urban environments where blue, green and grey functions interacts with generously with space underground for street vegetation. Under the ground surface, BGG systems are built up of BGG rain garden substrate and BGG open reinforcement layer (Edge, 2020):
    - BGG rain garden substrate: macadam, biochar (17 vol%) rock dust and green compost
    - BGG open reinforcement layer: macadam 32-63 or 32-90 and biochar (15 vol%)
- **Mixture into purchased soil substrates**:
  5-10 vol% biochar can be added to purchased soils to improve the soils water and nutrient holding capacity. Consider not charging the biochar with nutrients to avoid nutrient leakage.
- **Green roof substrate:**
  12.5 vol% biochar, 12.5 vol% green compost, 12.5 vol% gravel/sand 0-8, 62.5 vol% crushed tile 0-15 (Malmberg, 2022)
- **Contaminated soil**:
  The amount of biochar can potentially be significantly increased when applied in contaminated soil. Depending on the kind of contaminant, the properties of soil and plant species, the kind of biochar and amount (single or multiple dose application) would be adapted (Joseph, 2021).
- **Soil improvement, existing soils:**
  5 vol% biochar can be added to existing soils and green areas in the top 40 cm of soil (Alvem, 2022). Consider charging the biochar with nutrients to avoid nitrogen immobilization or not charging the biochar to avoid nutrient leakage – depending on the wanted effect and surrounding environment.

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