Urban Drawdown Initiative & Ithaka Institute

Urban Bioenergy-Biochar:
An Opportunity Assessment for Municipalities

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Executive Summary

The Urban Sustainability Directors Network in collaboration with the cities of Boulder, Helsinki, Minneapolis, and Stockholm engaged the Ithaka Institute to develop a high-level overview on the topic of converting urban waste streams into both bioenergy and biochar. This assessment included a survey of the organic materials generated within each city, existing and potential uses for excess heat generated during the carbonization process, urban uses for biochar, existing pyrolysis or gasification technologies capable of converting urban waste streams into both energy and biochar, a preliminary assessment of the potential climate impacts from carbonization of urban waste streams, a brief discussion of the variability of biochar's qualities and where biochar can be analyzed, and finally a discussion of the potential costs and revenue streams that are associated with carbonizing biomass.

Key insights and recommendations from this assessment include:

- Estimating the sequestration potential of biochar is highly variable but an example may provide some context for how to understand the potential impact on a city's overall GHG emissions. Relevant factors in the calculation include the amount of carbon content in the biochar (which varies depending on the original feedstock and production parameters), yield of biochar, and the carbon efficiency of the overall biochar production process. Biochar made from woody biomass has a high carbon content, often more than 90%. If we assume that a biochar plant produces 1,000 tons per year of biochar from 4,000 tons of dry woody biomass, the stabilized carbon produced is 900 kg. Carbon can be converted into CO2 (using 3.67 as a multiplier) but GHG emissions related to obtaining and carbonizing biomass as well as other considerations must be assessed and accounted for. A relatively conservative embodied carbon multiplier would reduce the 3.67 multiplier to 2.5. Therefore, for every 1,000 tons of this particular example of biochar buried in soils or in other long-life products 2,500 tons of CO2e is removed from the carbon cycle. Note that this calculation does not include any additional climate mitigation from the production of renewable energy or boosted photosynthetic capacity from the use of biochar in soils. One hundred of these small-scale biochar production plants (producing <3 tons per day of biochar) would retire roughly 17%, 5%, 10%, and 18% of current GHG emissions for Boulder, Minneapolis, Helsinki, and Stockholm respectively. A far more substantial contribution!

    - However, all participating cities have aggressive GHG reduction goals and when viewed in combination with reducing emissions by 80%, then these 100 production plants would be able to retire 86.6%, 23%, 47.9%, and 91.3% of GHG emissions respectively.

- Seventeen technologies that are currently available within the European or US marketplace that are capable of converting urban waste streams into both energy and biochar were identified. Additional bioenergy/biochar technologies that are still at pilot scale or are not yet permitted within Europe or the US or are focusing solely on agricultural residues at this stage have been listed as emerging technologies.

- There are a growing number of potential urban uses for biochar, several of which have been described within this report, including tree planting, turf and parks management, compost additive, bioremediation, stormwater management, construction materials (including concrete and asphalt), and water treatment. Additional emerging uses, which are showing promise but are only in the piloting phase, were identified but not discussed in detail. Certain end-use markets are more developed in some cities and regions, yet many, if not most, cities are largely unaware of the various ways biochar can be used in an urban context. Significant effort will be required to educate relevant stakeholders to increase awareness and begin piloting the use of biochar. As an example, tree planting with biochar is a well-established protocol in Stockholm and has been trialed in Minneapolis but is still unknown or in very early stages in other cities.

- Accurate, comprehensive data on total organics generated within the cities and surrounding suburbs is not readily available for all cities. Information on biomass handled directly by city agencies seemed to be more accessible but woody biomass handled by independent tree service companies or construction and demolition recyclers and their current end-use is not collected or summarized. It is recommended that cities begin to collect this information moving forward to have a better perspective on potential biochar feedstock.

- The availability of biomass for carbonization is not well understood. Woody biomass managed by contractors seems to already have alternative off-take agreements in some European cities, though insufficient information is available in terms of how much biomass handlers are currently paid for wood waste, which is sometimes used in district heating systems. In the future, city managers may want to consider retaining control of where biomass generated within the urban environment is sent.

- Long-term off-take agreements for sewage sludge may exist and be difficult to change in the short term, even if the current practice offers less climate-friendly benefits (e.g., incinerators versus pyrolysis). A better understanding of these types of contracts including the cost/benefit and carbon footprint of current organics management practices should be prioritized.

- Although insufficient biomass data were available to draw firm conclusions about the overall climate impact of carbonizing urban waste streams, it seems likely that cities will need to increase the number of trees within the greater metropolitan areas in order for the carbonization of urban biomass to have a significant drawdown impact. Tree planting, especially using biochar in the process, will enhance photosynthesis and carbon sequestration and as the wood waste from prunings will expand, the opportunity to produce bioenergy and biochar will increase. When contracts are up for renewal, consideration should be given to diverting organics towards facilities that optimize the carbon drawdown potential.

- Costs and revenues related to the pyrolysis of organic materials are highly variable depending on a number of factors including the ability to monetize different co-products; cost of biomass acquisition; labor; equipment acquisition and maintenance, and more recently, potential revenues from carbon removal markets. These factors are discussed briefly but in order for cities to have a better concept of costs and benefits, specific scenarios would need to be identified, as would relevant equipment and potential carbon removal off-take agreements.

Bioenergy-Biochar Feedstock Assessment

To understand the amount of biomass in each participating city, a survey was developed and later refined to ensure the reported information was more consistent across the four cities. Surveyed biomass included wood waste from tree management as well as clean wood waste from the construction industry, garden or green waste including grass and twigs, household food waste, and sewage sludge. Inorganic waste streams such as municipal solid waste were not included as this type of waste is outside of the acceptable feedstocks for biochar. Participants were later asked to differentiate between total biomass and biomass which is not already being used for district heating or otherwise unavailable (e.g., sludge sent to incineration facilities).

In addition to biomass information, the surveys solicited information on energy use, emissions, and other relevant data to facilitate estimation of the overall climate impact that bioenergy/biochar production could have, as well as possible costs and potential revenues based on three different production technologies. Responses were compiled by:

Boulder: Lauran Tremblay, Brett KenCairn
Minneapolis: Jim Doten
Helsinki: Susanna Kankaanpaa, Johanna Afhallstrom, Esa Nikunen
Stockholm: Björn Hugosson, Chief Climate Officer Stockholm, Britt-Marie Alvem, Charlotta Porso

A compilation of the responses is available upon request from the relevant cities. This summary document includes conversion of certain data (e.g., salaries, tipping fees, etc.) to US dollars to allow for easier comparisons across participating cities. Some per capita analysis was also added to facilitate comparisons. Several observations and conclusions can be drawn from the survey responses including:

- The total amount of different types of biomass is not something currently tracked by most cities. With the exception of Stockholm, the total volume of the four types of biomass generated in the metropolitan areas appeared to be either unknown or underestimated (e.g., amount of woody biomass in Helsinki). In order for a more accurate picture of the climate and economic impact of urban bioenergy/biochar production to be drawn, it is highly recommended that cities conduct a detailed biomass assessment or better yet, start to track this information on an annual basis as part of an overall carbon management program.

- In some cities, the availability of feedstock for bioenergy/biochar is variable and often unknown. While some cities generate significant woody biomass, in Stockholm this material is often handled by contractors who are paid to drop off woody debris at existing district heating plants. It is unlikely that this material would be diverted to pyrolysis plants unless contractors are paid similar amounts for drop-off or city contracts are amended. The economics of paying for feedstocks changes the cost/benefit calculations for carbonization. In Helsinki, the volume of materials handled by contractors is not known and assumed to either be chipped and fed back into urban forests or used for creating compost. Minneapolis is in the process of determining available biomass from the greater metropolitan area in order to understand what scale carbonization technology would be most appropriate. Further details were not available. Moving forward, cities may want to structure contracts in a manner where the biomass belongs to the city and could be delivered to biomass conversion plants.

- Long-term contracts for certain organics are in place in some locations making a transition to their use in bioenergy/biochar challenging in the short term. This includes sewage sludge going to incinerators, food waste to composters, or tree debris already being sold to district heating plants. As incineration in the US is facing increasing regulations and pushback from social justice organizations, many of the older plants are closing as the cost of meeting newer air emission regulations can be cost-prohibitive. It may be worthwhile to investigate the life expectancy for incineration plants that currently receive urban organics. If shutdowns are planned, converting to carbonization may be a welcome opportunity with significant drawdown benefits as well as other environmental benefits such as reduced water needs and less toxic waste handling.

- While the actual amount of urban biomass may be hard to pin down in some cities, it appears likely that the total biomass available for carbonization to support large-scale bioenergy/biochar production may be insufficient. Efforts to significantly increase the number of trees in the urban or metropolitan environment should be considered. When paired with the use of biochar in tree planting, the increase in tree growth and thus carbon sequestration could be significant. Scharenbroch et al., 2013 found an increase in tree growth of 44% and more recent studies have confirmed tree biomass increases with the addition of biochar (Somerville et al., 2020). The increase in tree prunings from the increased number of trees will also benefit bioenergy/biochar production and further enhance decarbonization efforts.

While diverting urban waste streams from existing management practices such as incineration, anaerobic digestion, or composting may be challenging due to existing off-take agreements, a review of the benefits and trade-offs of carbonization as compared to current practices, may convince city planners to start to shift organics management policies moving forward. A brief summary of the three most common organics management practices as compared to biochar is provided below.

Landfills

Landfilling remains one of the most common waste management practices, particularly in the US, though it is more limited in Europe. As current landfills reach capacity and as more states and nations are restricting what materials can be sent to landfills in an effort to reduce GHG emissions and odors, communities are looking for more sustainable alternatives. These include recycling, reducing single-use plastics, composting, anaerobic digestion, and more recently, conversion of certain waste streams into bioenergy and biochar. Carbonizing offers the following benefits over landfilling:

- Significant volume reduction of organic materials. Depending on production temperature and other variables, organics can be reduced between 70 – 95% by volume.
- Elimination of odors, many pathogens, and other chemicals of concern.
- Reduced groundwater contamination from landfill leachate.
- Significant GHG and especially methane reduction combined with carbon sequestration.

Biochar can also be used in and around landfills as a daily cover or as a liner under and around the landfill to mitigate leachate issues. It can also reduce odors and other emissions.

Anaerobic Digestion

Anaerobic Digestion (AD) has been used to manage food waste, animal manure, sewage sludge, and other organics for decades. It produces biogas, digestate, and effluent. In some cases, there is insufficient demand for the digestate which can become a bottleneck to scaling the use of AD. Co-location of AD and carbonization technologies can be very synergistic in a number of ways:

- Digestate can be converted into biochar,
- Excess heat from pyrolysis can be used to provide heat to the AD,
- Biochar can be used to filter the effluent which can serve to harvest nutrients from the effluent, and
- Biochar can be fed into the digester to enhance methane quality and quality while also reducing hydrogen sulfide.

Composting

Composting is also a common organics management process that converts food, grass, leaves, and other organic material into a rich soil enhancer. While carbonization and composting can be quite synergistic, there are certain advantages carbonizing offers such as:

- Significantly reduced time to convert organics into marketable products. Composting can take weeks while carbonizing can take minutes or hours.

- Volume reduction – composting can reduce volume by 20 – 60% whereas carbonization can reduce volume by 70 – 95%.
- Long-term Carbon retention is at least three times higher in pyrolysis than in composting.
- Compost tends to be a seasonally used product. As a consequence, more land is required for storing compost during the off-seasons when sales are low to non-existent.
- Certain organics such as woody waste, do not decompose quickly and may be better feedstock for biochar over composting.
- While composting produces fewer emissions than landfilling organics it still produces variable amounts of NH3, H2S, N2O, CH4, and VOCs, in some cases (e.g., with higher moisture content, higher bulk density, and lower C/N ratios) these can be significant (Cerda et al., 2018). Carbonization is likely to produce fewer emissions.
- Some compost operations attract pests and emit odors. These are eliminated with carbonization.
- Not all toxins such as pesticides, herbicides (e.g., Clopylarid), and bacterial pathogens are eliminated during the composting process. Thermo-chemical conversion will eliminate all of these.

As with AD, a combination of compost and biochar can be synergistic. Blending compost with biochar has been found to provide a number of benefits which are discussed in the biochar utilization opportunities section.

Incineration

Incineration is a thermal waste treatment process for organic material often referred to as waste to energy facilities. Key attributes of this method include volume reduction up to 96% and destruction of certain hazardous waste materials. However, the fly ash that results from incineration can contain toxic heavy metals and dioxins and must be sent to a hazardous waste landfill. Emissions are also a concern, particularly for older facilities, and a majority of the 72 incineration plants in the US are 25 years old or older. A majority of the US facilities are also located in areas with high poverty or significant minority populations which are increasingly pushing for these plants to be closed.

It should be noted that in some areas, there is a tendency to conflate incineration, gasification, and pyrolysis. It is critical to educate policymakers and the general public about the differences between these thermochemical conversion processes and their environmental impact. Ensuring that waste streams are properly sorted and that only organic materials are utilized for bioenergy and biochar production mitigates the potential for toxins either in emissions or in the resulting biochar. Converting from incineration to carbonization would reduce costs related to dealing with toxic waste streams, reduce GHG and other toxic emissions and increase revenue streams from both biochar and carbon credits.

Bioenergy-Biochar Applications

While biochar production has been gaining momentum over the past few years, most of the production has happened outside of urban environments. Carbonizing farm and forestry waste has been gaining traction as this method of organics management offers several advantages over current organics management practices including rapid volume reduction, reduced transportation of organics, and reduced fire risk which is a key concern in heavily forested regions. Urban adoption of carbonization as a preferred organics management practice is in the very early stages in a few cities but still largely unknown by most city officials.

Bioenergy Applications & Assessment

Depending on the moisture content of the feedstock, excess heat can be a highly valued co-product from pyrolysis or gasification which can be harnessed for a variety of uses. Wetter feedstocks (e.g., biosolids, manures) often have 80% moisture content or more so the heat generated is generally used to dry the biomass prior to thermochemical conversion leaving little excess heat for other uses. However, carbonizing dryer feedstocks can generate significant amounts of excess heat. Most commonly the excess heat is used for space heating or to generate electricity. More recently the heat is being used in a broader variety of process heating applications including water heating for a shrimp farm.

Some of the most common producers of biochar in the U.S. are traditional biomass energy plants that produce a high carbon co-product. Humboldt Sawmill operating since 1989 in Scotia, California is a good example. They produce 25 MW of renewable energy from 150,000 – 200,000 bone dry tons of biomass from forests, sawmills, and urban biomass. In addition to the main energy product, they produce a high carbon consistent biochar which is marketed by Pacific Biochar as a compost additive and for direct soil application. This biochar passed all safety tests and was the first U.S. producer to receive carbon removal credits on the Carbon Future platform.

Gasification technologies are also capable of producing syngas that can be used to generate electricity while concurrently producing biochar in variable amounts. Aries Clean Technology operates a plant in Lebanon, Tennessee that converts 23,000 tons of waste wood from pallets and crates per year into 420 kW of electricity, which is utilized by a nearby wastewater treatment plant. In addition, it produces 3,500 tons of biochar per year which is sold for both agricultural and non-agricultural uses. Syncraft is an Austrian technology company that designs and manufactures floating fixed bed gasifiers that produce electricity, heat and between 5 – 15% biochar by volume of feedstock. They have plants operating in Austria, Italy and are opening plants in Japan, Germany, Croatia, and Switzerland. Various sizes are available to produce 3,000 – 30,000 kW of electricity and up to 45,000 kW heat which is most often connected to district heating systems. Their largest plant will be producing 3,000 Mt of biochar per year.

District heating is far more common in Europe than in the U.S. and provides an excellent seasonal off-take opportunity for excess heat from thermochemical conversion (TCC). Pyreg (Germany) and Carbofex (Finland) design and manufacture pyrolysis equipment that is currently putting heat into district heating systems in Northern Europe. The most well-known and possibly first demonstration of this was in Stockholm, Sweden where yard waste is being converted into heat for the district heating system and biochar using a Pyreg system. This pilot has inspired a growing number of cities in Europe to adopt similar strategies using different pyrolysis technologies.

Other examples of space heating generated from excess heat from pyrolysis can be found in the agricultural sector, particularly in greenhouses. Rainbow Bee Eater’s (Australia) ECHO2 system is providing heat and electricity to a large greenhouse while concurrently generating biochar. They are using waste wood provided by a local composting operation who then utilizes the biochar in their compost operation.

Apart from space heating, there is an almost endless number of ways industries use process heat, much of which is currently derived from fossil fuels. It is critically important to differentiate between using the heat from pyrolysis for these processes versus using the biochar generated from the pyrolysis process as a substitute for coal and other fossil fuels to generate heat. The former can be a carbon-negative process whereas the latter can, at best, be a carbon-neutral technology. Both are needed to decarbonize current energy-intensive industries but it is important to understand the difference between biochar and charcoal. Charcoal has traditionally been used as a term to describe carbonized biomass used for heating or cooking. Biochar, while it looks very similar to charcoal, is used to describe carbon made for organic sources and used in ways that prevent the carbon from returning to the atmosphere. Some producers of charcoal are now actively seeking out biochar markets. As charcoal is often produced at lower temperatures, it is important to understand the characteristics of the material before testing it in soils or other materials.

A U.S. perspective on process heat is outlined in Table 1. Of these, drying of feedstock for use in carbonization is perhaps the most commonly applied use for CHAB systems.

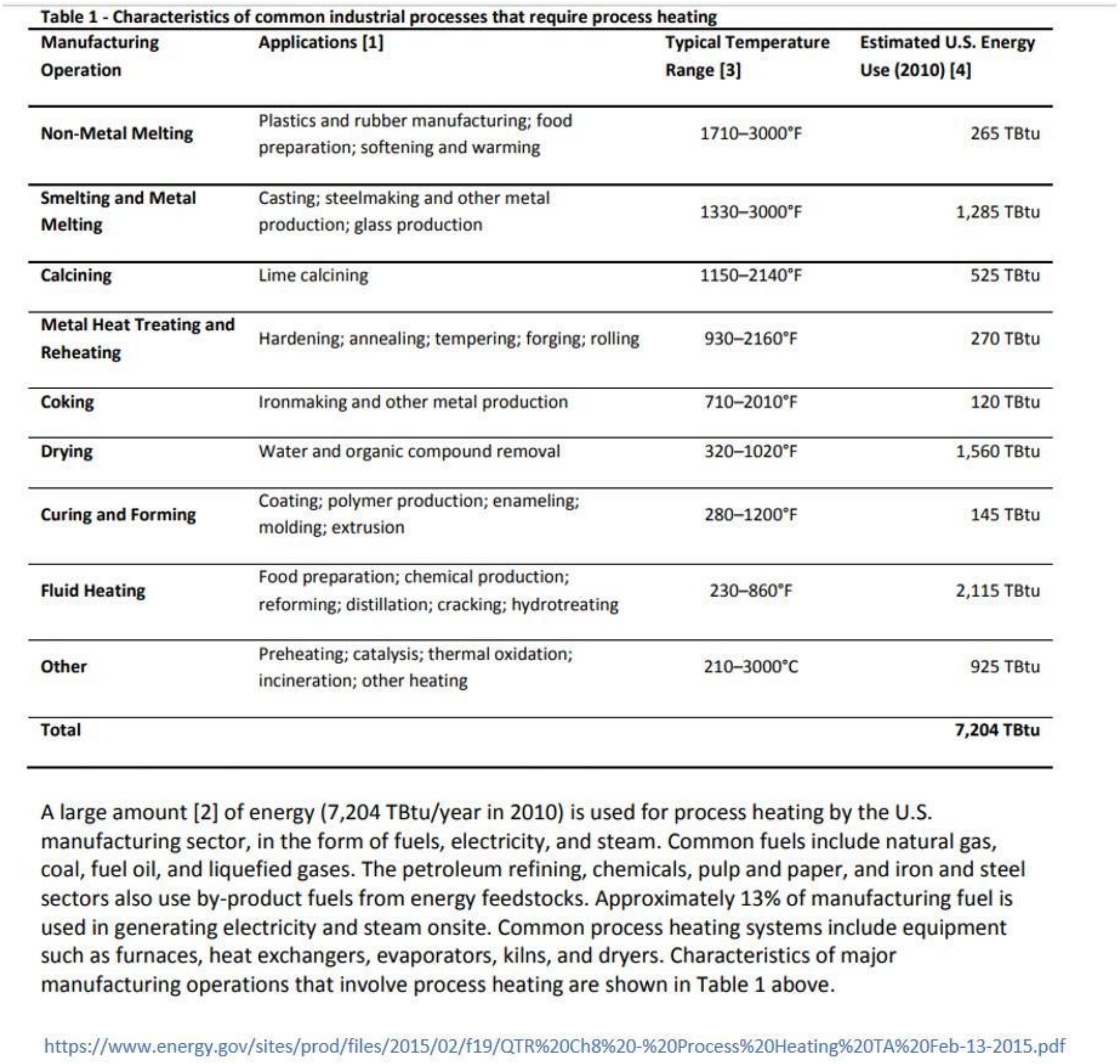


Table 1 - Characteristics of common industrial processes that require process heating

Manufacturing Operation	Applications [1]	Typical Temperature Range [3]	Estimated U.S. Energy Use (2010) [4]
Non-Metal Melting	Plastics and rubber manufacturing; food preparation; softening and warming	1710–3000°F	265 TBtu
Smelting and Metal Melting	Casting; steelmaking and other metal production; glass production	1330–3000°F	1,285 TBtu
Calcining	Lime calcining	1150–2140°F	525 TBtu
Metal Heat Treating and Reheating	Hardening; annealing; tempering; forging; rolling	930–2160°F	270 TBtu
Coking	Ironmaking and other metal production	710–2010°F	120 TBtu
Drying	Water and organic compound removal	320–1020°F	1,560 TBtu
Curing and Forming	Coating; polymer production; enameling; molding; extrusion	280–1200°F	145 TBtu
Fluid Heating	Food preparation; chemical production; reforming; distillation; cracking; hydrotreating	230–860°F	2,115 TBtu
Other	Preheating; catalysis; thermal oxidation; incineration; other heating	210–3000°C	925 TBtu
Total			**7,204 TBtu**

A large amount [2] of energy (7,204 TBtu/year in 2010) is used for process heating by the U.S. manufacturing sector, in the form of fuels, electricity, and steam. Common fuels include natural gas, coal, fuel oil, and liquefied gases. The petroleum refining, chemicals, pulp and paper, and iron and steel sectors also use by-product fuels from energy feedstocks. Approximately 13% of manufacturing fuel is used in generating electricity and steam onsite. Common process heating systems include equipment such as furnaces, heat exchangers, evaporators, kilns, and dryers. Characteristics of major manufacturing operations that involve process heating are shown in Table 1 above.

https://www.energy.gov/sites/prod/files/2015/02/f19/QTR%20Ch8%20-%20Process%20Heating%20TA%20Feb-13-2015.pdf

Biochar Utilization Opportunities

While traditionally viewed as a soil amendment for agriculture, the number of uses for biochar has been expanding over the past several years. Many of these uses are directly applicable to urban environments. In some cases, biochar can be used in a cascading scenario (e.g., first used to adsorb nutrients in effluent and subsequently used to enrich soils). This report outlines some of the more shovel-ready urban uses of biochar. We note that across the globe there are wide variations in culture and practice so some of these end uses will not be applicable in all cities (e.g., the use in landfills as discussed above may be more appropriate in the U.S. than in Europe). For each of these uses, the relevance or value of using biochar as compared to current practices is discussed, as is the market readiness. Where possible, examples of cities currently using biochar in this manner are provided. Materials that biochar is displacing and potential barriers to widespread adoption are also discussed.

Tree Planting

Planting trees in urban environments using biochar has been happening for many years. Stockholm was likely one of the first urban environments to develop and broadly deploy the use of structured soils with biochar for the purpose of increasing tree longevity. Urban trees often suffer from a variety of grievances not normally experienced by trees grown in more natural environments. Pollutants in the air and from roads, compacted soils, limited space for root and crown growth, all can contribute to less robust trees that are more susceptible to insects and disease. Climate change is also increasing heat island impacts and exposure to extreme drought and/or flooding which further add to urban tree stress. Adding biochar to soils around trees can address several of these afflictions. The porous nature of biochar reduces soil compaction, improves water management in soils (Somerville et al., 2020), and provides a safe habitat for microbial communities. Biochar is capable of filtering and immobilizing toxins that accumulate in soils. Alleviating some of these pressures can boost a tree's ability to fight off pests and pestilence.

While it is easiest to add biochar to trees when they are initially planted, there are various ways to incorporate biochar into the root zone of existing urban trees. In Stockholm and other European cities, the soil around existing trees is removed and replaced with pre-blended structured soil made up of gravel, biochar, and compost. In some cases, a layer of pure biochar is first added to the hole or trench to further increase filtration capabilities. This system of adding biochar in a structured soil can be costly and involves significant equipment to excavate and transport current soils and replacement structured soils. Although expensive, the benefits in keeping existing trees, increasing the capacity for stormwater retention, and using urban waste in a beneficial manner should not be discounted. A less invasive method for adding biochar involves injecting compressed air to create voids approximately every meter, ideally beyond the tree's drip line – though this isn't always feasible in urban environments. The voids help decompaction of soil and are then filled with roughly 1 kg of biochar per void. (An example of this technology is the Geoinjector made by Vogt). The Ithaka Institute was one of the first to use the Vogt Injector and helped to optimize it for injecting biochar.

Currently, the most common type of biochar used for urban tree planting is made from woody biomass, though various types of biochar could potentially be used in tree planting depending on the main objectives for using biochar in urban trees. The IBI or EBC standards for use in soils should be adhered to in order to ensure that the biochar is low in toxins and is eligible for carbon removal credits.

The material being displaced in this scenario is either soil or, in some cases, compost. While biochar is more costly than either of these amendments, the overall cost for improving the health of urban trees or replacing them can be high. So in terms of the overall cost of urban tree planting, the cost of the biochar is low. In addition, the biochar will likely provide more benefits (e.g., filtration of heavy metals) over a longer period of time.

Turf/Parks Management

Urban soils may include soils in parks, sports fields, gardens, forests, along roadsides, and small yards for certain urban dwellers. These soils often suffer a myriad of problems including compaction, poor aeration and drainage, contamination from excess herbicides, fertilizers and chemicals, erosion, and poor nutrient management. Maintaining healthy urban soils can be a challenge given multiple stresses and mounting costs. Utilizing biochars made from urban waste streams may be a cost-effective way to improve urban soil health, reduce the use of external inputs such as fertilizer, all while reducing problematic waste streams. Sewage sludge biochars have increased the dry matter in turf from 43 – 147% while also improving nutrient management (Tien et al., 2019). *It should be noted that in Europe, regulations prohibit the use of this type of biochar from being land applied.* Larger-sized particles of biochar can improve aeration, alleviate water stress and lead to improved plant growth (Yoo et al., 2020). Biochars made from wood waste may need to be blended with compost to boost microbial activity and nutrients in turfgrass soils (Azeem et al., 2020).

Compost Enhancement

While some might consider composting and carbonization to be competitive waste management strategies, there are, in fact, significant synergies to co-composting with biochar. Composting most kinds of heterogeneous food waste is often a better option than carbonization as food waste can be quite variable which results in inconsistent quality biochar. Wood waste or other more homogenous food residues may make better feedstock for biochar production as these will result in a more consistent and higher carbon content product.

The compost industry is currently one of the largest buyers of biochar in the U.S. This is likely due to the many benefits that adding biochar can bring to composting operations. Amongst these benefits are:

- Accelerated compost maturity (Kaudal et al., 2018, Xiao et al., 2017) – i.e., reduction in the time needed to create a finished product
- Reduced loss of nutrients, particularly nitrogen (Guo et al., 2020)
- Reduced emissions including CH4, N2O, and NH3 when 10 – 30% biochar used (Sanchez-Monedero et al., 2018)
- Longer lasting carbon (Guo et al., 2020)
- Herbicides and other toxins which are increasingly present in manures or sludge can be inactivated (Guo et al., 2020)
- Levels of antibiotics can be significantly reduced (Kui et al., 2020, Shan et al., 2018)
- A reduced bulk density can facilitate aeration
- Fewer odors
- An increased temperature within the compost can help eliminate more pathogens, and
- Immobilization of certain toxins (e.g., herbicides, pesticides, heavy metals, etc.) that may be found in certain waste streams such as manure (Sanchez et al., 2018).

Typically, adding 10% (by volume) biochar is sufficient to enhance composting though up to 70% still shows benefits. Key biochar properties for use in compost include porosity, surface area, and cation exchange capacity (Godlewska et al., 2017Sanchez-Monedero et al., 2018).

Bioremediation

Biochar is increasingly used as an in-situ method of remediating contaminated soils. Different biochars have been shown to effectively reduce different heavy metal(oid)s, excess fertilizers, pesticides, and other emerging contaminants of concern such as PFAS. Biochar high in phosphorus, such as biosolids biochar heated to at least 400C, can effectively reduce the bioaccessibility of lead in urban soils (Netherway et al 2019). Low-temperature sewage sludge biochars can also reduce the accumulation of Cr, Cd, Cu, Mn, Pb, and Zn in turfgrass (Tien et al., 2019).

Pesticide use in urban environments is both extensive and intensive as urban dwellers seek to keep various types of pests at bay while also maintaining their lush, yet limited, landscapes. These chemicals all too often find their way into the air, soil, and waterways due to spills, leaks, improper storage, transportation, and general use. By adding a layer of biochar near the soil surface, the leaching of certain pesticides (e.g., diuron, MCPA) can reduce the negative impact on groundwater and human health (Cederlund et al., 2017). Biochar layers of 9cm and 16cm would be needed to eliminate leaching for diuron and MCPA respectively. It is important to understand which pesticides are being targeted for mitigation as the efficacy of different biochars varies based on production conditions.

The use of excess fertilizer has led to many environmental problems such as eutrophication or dead zones, lower water quality, and higher wastewater treatment costs. Biochar may be used to slow down N-transportation while still being available to plants (Hestrin et al., 2019). It can also help reduce P leaching (Zhang et al., 2020) thereby reducing negative impacts on ground and surface water.

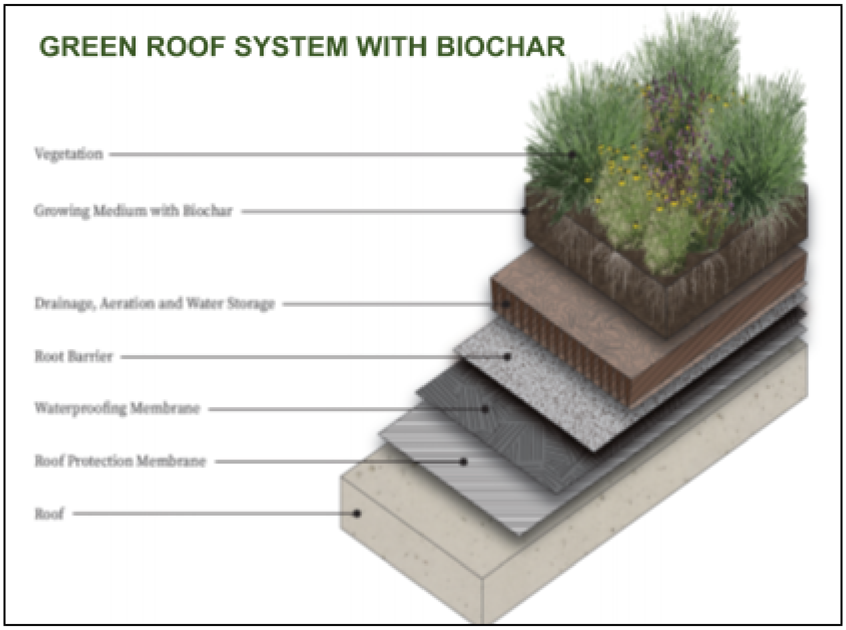
Per- and polyfluoroalkyl substances (PFAS) are a growing concern in cities, suburbs, and rural areas. These 100+ manmade ‘forever chemicals’ can be found in soils, rivers, groundwater, and increasingly in drinking water across the globe. The sources are many: firefighting foam, certain food packaging (e.g. pizza boxes), Teflon cookware, cleaning chemicals, and more. The cumulative health impacts on humans are assorted and often extreme. Certain remediation options are limited and expensive in terms of costs, energy, and water requirements. Activated carbon or woody biochar can be a solution in stabilizing contaminated soils (Sørmo et al., 2021).

Stormwater Management

More frequent and intense rainfall hitting impervious city pavements is leading to frequent flooding as urban stormwater drainage systems are increasingly overwhelmed. Upgrading and adding capacity to slow, dispatch, filter, and store large volumes of water quickly is an urgent priority for a growing number of cities. Mitigating or avoiding the adverse effects of flooding has necessitated increased stormwater management strategies. Low Impact Development (LID) includes systems that mimic natural processes and includes bioretention, rain gardens, green roofs, permeable pavements, bioswales, etc. A few of these strategies and how biochar can be incorporated to improve their efficacy and impact are discussed below.

Green Roofs -- Green roofs offer many benefits from reducing the heat island impact to lowering energy bills. Stormwater management may be one of the most vital public benefits as green roof substrates can retain up to 90% rainfall in summer and 40% snowfall in winter. A report from Kansas City showed a net runoff reduction from 32.3 inches in a conventional roof to 3.3 inches in a green roof (US EPA, 2018). Not only do they slow down volumes of water during extreme rain events going into sewage systems, but they also filter runoff which reduces contaminants. A variety of materials can be used in green roof substrates including ash, coir, bark, compost, crushed ceramics (bricks, tiles), scoria rock, perlite, pumice, synthetic additives, and sand. The relevant properties for green roof growing mediums include infiltration rate, longevity, weight, resistance to decomposition and compression, saturated bulk density, air-filled porosity, water holding capacity, pH, electrical conductivity, cation exchange capacity, and physical as well as chemical stability.

Biochar can improve green roof growing mediums in a number of different ways. One study showed how it can significantly improve water holding capacity (Cao et al., 2014). The plant available water reduces the permanent wilt point enabling a wider variety of drought-tolerant plants to be used. The reduced bulk density compared to certain substrate materials means that 1.5 cm/m2 could be added allowing for deeper roots. Pollutants such as total Nitrogen and chemical oxygen demand (COD) can be reduced with biochar usage (Qiangian et al., 2019).



Researchers in Nanjing, China found that sludge biochar usage could store up to 9.3 kg of Carbon per m-2 (Chen et al., 2018). There is some indication that biochar made from low-density wood is better at storing plant available water while also being lighter than biochar made from high-density wood (Werdin et al. 2019).

Rain Gardens/Bioretention -- Another rainwater runoff reduction remedy is rain gardens, also referred to as bioretention. Rain gardens consist of a depressed area that enables rainwater to be collected and soak into the ground. Traditional media used in bioretention schemes include sand, soil, mulch, and/or compost. Biochar could easily be substituted or blended with these materials.

Structured Soils/Permeable Pavements -- As previously described the use of biochar blended with other materials into structured soils can be used to significantly increase both infiltration and filtration of stormwater.

Construction Materials

One of the markets garnering the most excitement recently within the biochar industry is in construction materials including asphalt and concrete. Not only does the inclusion of biochar in these widely used materials provide an enormous carbon sink opportunity, but biochar produced materials from local waste organics can also displace high embodied carbon materials leading to further decarbonization.

Research into the benefits of using biochar and pyro-oil in asphalt has expanded quickly over the last few years as have commercial pilots in Australia and Europe. Asphalt production and use off-gasses significant amounts of VOCs which contribute to urban haze and can be detrimental to human health. Embedding woody biochar into asphalt can reduce up to half of these emissions (Zhao et al., 2020). Improved anti-aging properties is another benefit of adding biochar to asphalt (Dong et al., 2020) which means fewer road repairs which will help cities reduce transportation maintenance costs and emissions.

Pilot-scale commercialization efforts are underway and have shown great potential for storing vast amounts of carbon. CarbonCor has successfully used up to 30 tons of various different types of biochar per kilometer of road (IBI webinar, 2020) in their cold mix asphalt. They have also used up to 300 tons per kilometer in the subgrade layers. The use of biochar in more traditional hot mix asphalt has been trialed in Europe in 2020. By reducing asphalt filler content from 10% to 8% with 2% biochar by dry weight was sufficient for typical roads to become climate positive. Efforts are underway to update European standards to allow for the use of increasing amounts and types of biochar as an approved filler material for road construction. To put this in a global context, the global annual demand for asphalt is estimated at 143M Mt. At the lowest filler rate of 2%, this could provide a safe and beneficial repository for 2.86M Mt of biochar. Using the calculations provided previously (biochar with 90% carbon and a multiplier of 2.5), this would sequester more than 7M Mt of CO2e annually.

Adding biochar to concrete is also starting to move from labs to commercialization, albeit more slowly. Snøhetta, a Norwegian architecture and landscape design firm, recently trialed the use of biochar in concrete walls. Benefits to adding biochar to concrete include reduced density and weight, improved sound absorption, and insulation (Cuthbertson et al., 2019). It can also reduce concrete permeability and thermal damage while increasing compressive strength (Gupta et al., 2020). Water vapor resistance can be improved by 50% while also improving humidity control and reducing mold growth (Park et al., 2021).

The specific end-use of the concrete is a major determinant of the amount of biochar that could be added as too much can decrease certain properties such as tensile strength. The addition of .5% - 8% by weight has been commonly researched which could lead to substantial carbon sequestration. Standards for concrete additives may need to be updated for broad adoption of the use of biochar in concrete to occur.

Water Treatment/Filtration

Biochar is increasingly being viewed as a cost-effective, environmentally sustainable medium for various types of wastewater treatment (e.g., industrial, municipal, agricultural) to filter out contaminants such as heavy metals and organic pollutants as well as to harvest excess nutrients which can cause significant environmental impacts downstream. It can also reduce chemical oxygen demand (COD) and total suspended solids (TSS).

Using biochar to filter wastewater resulting from food production can enhance the biochar as it absorbs nutrients such as phosphorus, potassium, or nitrogen. This has the effect of converting the biochar into a slow-release fertilizer (Barber et al., 2018, Haddad et al., 2021), which is able to enhance agronomic yields and reduce the need for expensive and GHG producing chemical fertilizer. This type of cascading use of biochar could help reduce its cost leading to increased market demand.

Biochar has been shown to help filter out a wide spectrum of contaminants found in municipal wastewater including heavy metals, (Xiang et al., 2020), PFAS (Kundu et al., 2021), and E.coli (Valenca et al., 2021). Biochar may be a more cost-effective alternative to activated carbon, which is often imported for use in water filtration.

Additional carbon sink opportunities for biochar that may be relevant for cities but are not yet in widespread use include:

- Septic systems to reduce nutrient and toxic leaching,
- Cemeteries to avoid leaching of heavy metal & embalming toxins,
- Composites for building and packaging materials,
- Landfills as daily cover and/or leachate treatment, and
- Municipal office greening (indoor plants).

Bioenergy-Biochar Production Technologies

Thermochemical conversion of biomass includes various technologies such as pyrolysis (pyrolysis technologies include slow, fast, flash or microwave), gasification, combustion and incineration. The scope of this report focuses on pyrolysis and gasification equipment that can not only produce biochar but is capable of utilizing the excess heat generated during production. [In the biochar industry these types of systems are referred to as CHAB – combined heat and biochar.] In addition, only technologies that can process organic materials produced in cities will be included. This omits a number of current technologies that focus solely on agricultural residues (e.g., manure) which may, in the future, be appropriate for urban waste streams. This section provides a brief overview of technologies in use in the United States and Europe. Additional information on some of these and other technologies are available through the International Biochar Initiative's guide to 'Choosing a Biochar Reactor to Meet Your Needs' which outlines a wide variety of batch and continuous feed systems, including both small and industrial-scale technologies. The US Biochar Initiative also recently developed a white paper that looked at CHAB technologies available in the United States that could operate within a composting operation.

It should be noted that some existing biomass energy plants may be able to be converted to produce biochar in addition to bioenergy. As noted previously this is starting to happen in the United States, particularly in California, as the demand for biochar and biochar carbon removal credits begins to increase. In cities that already have bioenergy-based district heating, it may be worth investigating if this is a possibility as it may be the least expensive way to begin urban biochar production. Additional biomass would be required to generate the same amount of bioenergy, but the infrastructure is likely already in place for any preprocessing (e.g., chipping, drying).

As the landscape for carbonization technologies is rapidly changing with new technologies coming online every few months, this report is not intended to be comprehensive, nor is it meant as a recommendation of any particular technology. The selection of the most appropriate technology should be determined based on quantity, quality, consistency, and moisture content of biomass amongst other variables. In addition, desired co-products such as heat, electricity, syngas, bio-oils, and/or wood vinegar are critical factors in determining the most appropriate technology for a given scenario.

Current

The number of CHAB technologies has been increasing steadily over the past several years though most of the biochar production technologies and the companies that manufacture them are still quite small. TCC equipment now comes in a wide variety of scales, producing different combinations of co-products, and able to carbonize an ever-larger variety of biomass. Increasingly, these technologies are continuous feed systems versus batch but there are exceptions (e.g., Polytechnik). Several are modular systems that allow for increased production as demand for biochar or other co-products increases. A shortlist of 17 technologies is provided below and further information on these technologies can be found in Appendix A. These technologies were selected based on the following criteria:

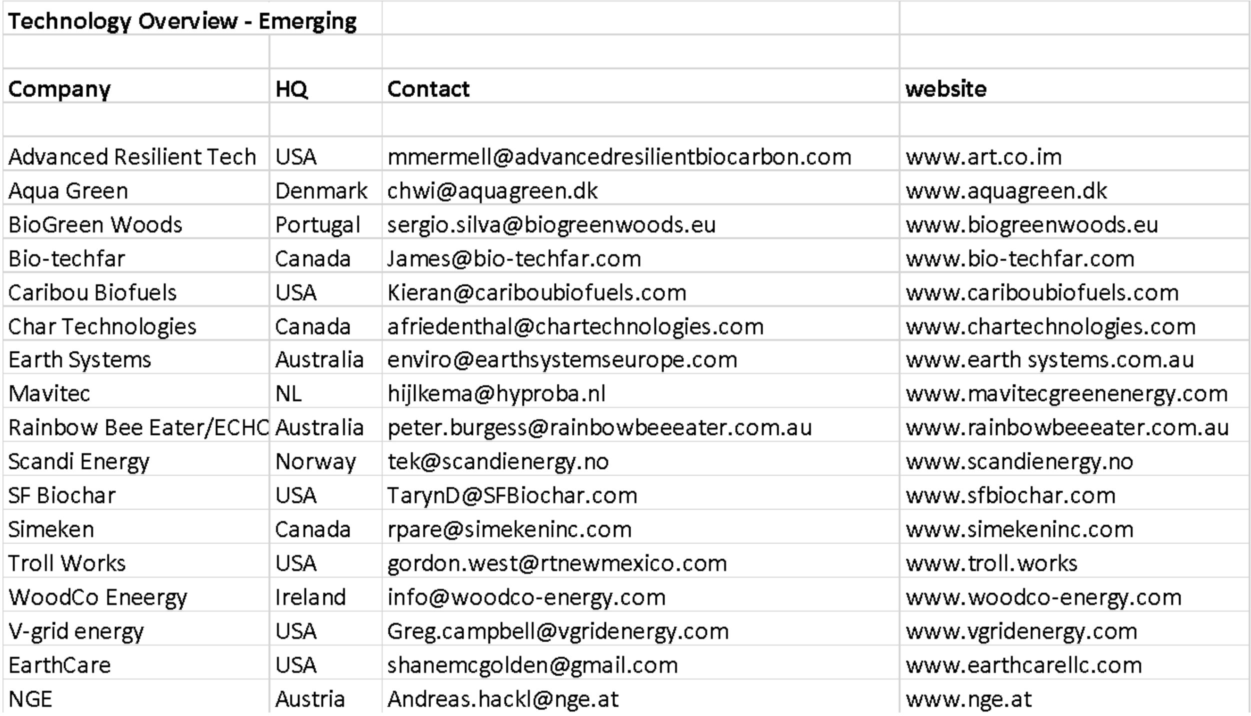
- Currently operating a plant in the US or Europe – an important consideration as adopting equipment to comply with air quality emissions, labor safety, and electrical regulations can be time-consuming and expensive. It is also critical to have locally, or at least nationally, available technical support.
- Currently used to carbonize urban feedstock. Several TCC technologies only focus on manure, agricultural waste, tires, plastic, or other non-organic or disqualifying feedstocks in terms of biochar. A selection of these was listed on the emerging list.
- Capable of harvesting heat for use in drying, room or building heating, or other process heating needs in addition to producing biochar. Several systems do not inherently harvest heat but can be configured to do so using compatible technologies.

Company	HQ	Contact	Geography	Type	Feedstock	website	email
All Power Labs	USA	Alejandro Abalos	worldwide	Gasifier	woodchip	www.allpowerlabs.com	alejandro@allpowerlabs.com
ARTi Char	USA	Bernardo del Campo	worldwide	Mobile Retort	various	www.arti.com	bernidc@gmail.com
Biomass Controls	USA	Jeff Hollowell	worldwide	Pyrolysis	various	www.biomasscontrols.com	jeff@biomasscontrols.com
Pyreg	Germany	Helmut Gerber	worldwide	Pyrolysis	wood, sludge	www.pyreg.com	h.gerber@pyreg.de
Pyrocal	Australia	James Joyce	worldwide	Furnace	various	www.pyrolcal.com.au	james.joyce@pyrocal.com.au
VOW (Scanship + Etia)	Norway	Nataliia Kaisen	worldwide	Pyrolysis	various	www.vowasa.com	nataliia.kasian@scanship.no
Biomacon	Germany	Tomas Hoffman	Europe, India	Pyrolysis	various	www.Biomacon.de	th@biomacon.com
Carbofex OY	Finland	Sampo Turkeinen	Europe	Pyrolysis	woodchip	www.carbofex.fi	
Carbon Technik Shuster	Germany	Nabil Linke	Europe	Pyrolysis	pellets	www.ct-schuster.de	n.linke@carbex.one
Polytechnik	Austria	Viktor Radic	Europe	Retort: batch	woodchip	www.biomass.polytechnik.com/en/	v.radic@polytechnik.at
Scandi Energy	Norway	Toralf Ekelund	Europe, Africa	Gasifier	wood, MSW	www.scandienergy.no	tek@scandienergy.no
Syncraft	Austria	Marcel Huber	Europe, Japan	Gasifier; floating fixed b	woodchip	www.syncraft.at	marcel.huber@syncraft.at
Aries Clean Tech	USA	Joel Thornton	USA	Gasifier	wood, sludge	www.ariescleantech.com	Joel.Thornton@AriesCleanTech.com
Biomass Energy Techniques	USA	Joel Toth	N America	Pyrolysis & Gasification	wood, hemp	www.biomassenergytechniques.com	joelt@biomassenergytechniques.com
ICM	USA	Bert Bennett	Americas	Updraft Gasifier	wood	www.icminc.com	Albert.Bennett@ICMINC.com
Organilock	USA	Scott Laskowski	USA	Furnace	woodchip	www.organilock.com	scott@organilock.com
TrollWorks	USA	Gordon West	USA	Pyrolysis	various	www.troll.works	gorwest4@gmail.com

While many of these companies are beginning to market their technology globally, it is important that those looking to import TCC equipment understand what modifications to technologies are required in order to meet different regulatory and permitting standards, who will be responsible for making these changes, how costly will changes be, and how long permitting might take for new equipment. Sourcing production technology from abroad can also prove challenging, costly and cause delays in production if parts and experienced technicians need to be flown in from abroad.

Emerging

In the emerging category, we include technologies that are not currently available in Europe or the U.S. but are operational elsewhere, technologies that are still permitting their first production plants, or technologies that are currently focusing on non-urban residues that may be able to carbonize urban residues in the near future. It is relevant to note that the pandemic has had a significant impact on bioenergy/biochar production plants becoming operational due to supply chain slowdowns as well as travel and social distancing restrictions. Several plants that were scheduled to open in 2020 have been delayed until 2021 and are therefore included in the emerging section. This list is by no means exhaustive as there is an increasing number of technologies looking for national or regional partners to collaborate to import less expensive technologies from Asia which can be customized to meet local air quality, safety, and electrical standards.



Technology Overview - Emerging

Company	HQ	Contact	website
Advanced Resilient Tech	USA	mmermell@advancedresilientbiocarbon.com	www.art.co.im
Aqua Green	Denmark	chwi@aquagreen.dk	www.aquagreen.dk
BioGreen Woods	Portugal	sergio.silva@biogreenwoods.eu	www.biogreenwoods.eu
Bio-techfar	Canada	James@bio-techfar.com	www.bio-techfar.com
Caribou Biofuels	USA	Kieran@cariboubiofuels.com	www.cariboubiofuels.com
Char Technologies	Canada	afriedenthal@chartechnologies.com	www.chartechnologies.com
Earth Systems	Australia	enviro@earthsystemseurope.com	www.earth systems.com.au
Mavitec	NL	hijlkema@hyproba.nl	www.mavitecgreenenergy.com
Rainbow Bee Eater/ECHC	Australia	peter.burgess@rainbowbeeeater.com.au	www.rainbowbeeeater.com.au
Scandi Energy	Norway	tek@scandienergy.no	www.scandienergy.no
SF Biochar	USA	TarynD@SFBiochar.com	www.sfbiochar.com
Simeken	Canada	rpare@simekeninc.com	www.simekeninc.com
Troll Works	USA	gordon.west@rtnewmexico.com	www.troll.works
WoodCo Eneergy	Ireland	info@woodco-energy.com	www.woodco-energy.com
V-grid energy	USA	Greg.campbell@vgridenergy.com	www.vgridenergy.com
EarthCare	USA	shanemcgolden@gmail.com	www.earthcarellc.com
NGE	Austria	Andreas.hackl@nge.at	www.nge.at

Preliminary Climate Impacts Assessment

Based on the biomass information supplied by each city, the current C-sink potential from biochar is quite low, with Stockholm being the highest at nearly 4% and each of the other cities being less than 1%. This is likely due to the lack of information on the total biomass generated and available in each city. A form that provides the high-level data of C-sink potential as it relates to current emissions is available upon request. This form can be updated as urban carbon managers refine their biomass estimates and begin to reduce their emissions.

It should be noted that the C-sink potential should not be looked at in isolation but should rather be looked at in tandem with reduction goals and efforts to boost urban photosynthesis. If, and hopefully when, cities are able to reduce emissions by 80% or more, the contribution that biochar can make to net-zero goals begins to look much more meaningful. In Stockholm, it would be close to 20%.

Biochar Characterization and Specifications

It cannot be said often enough: all biochars are not the same. Though all biochars, at least when ground up to a powder, look very similar, their physical, chemical, biological, and electromagnetic properties differ considerably. These properties vary based on the feedstock used to create the biochar as well as certain processing parameters such as type of processing equipment, highest heating temperature, and residence time (i.e., amount of time the material is heated). The characteristics of the biochar can have a large impact on its usefulness in different applications. Ideally, when deciding what type of biochar to produce from urban waste, the end-use should be kept in mind. When deciding what kinds of biochar would be most beneficial to a city, urban carbon managers should consider and prioritize what local problems biochar can best help mitigate, what high cost or high embodied carbon or imported materials could be displaced by biochar, as well as the potential sequestration impact.

Historically, the term biochar has been used to refer to stable carbon made from organic materials that is used in a manner that prevents plant carbon from returning to the atmosphere. Standards have been and continue to be developed to help define what materials can be considered as biochar. These standards mainly focus on persistence or resistance to decay as measured by the hydrogen to carbon (H:C) ratio, a minimum carbon content, and safety (i.e., low levels of toxins in the form of heavy metals, PAHs, etc.). The International Biochar Initiative (IBI) and the European Biochar Certificate (EBC) have both developed standards for biochar which can be found here: Biochar Standards - biochar-international (biochar-international.org); The European Biochar Certificate (EBC) (european-biochar.org). Currently, IBI has one standard for biochar use in soils and the EBC has four standards which include two for use in soils as well as a livestock feed standard and materials standard. Both the IBI and EBC are working on developing additional standards for more recent end uses.

While these standards provide important guidelines for the use of safe biochar, they do not necessarily outline the range of optimal biochar characteristics for various uses discussed previously. This is an area of ongoing research to understand which biochar characteristics are most important for different end uses and what the ranges are for those characteristics. As an example, in drought-prone areas where biochar is used largely to improve water management in sandy soils, the most relevant characteristics might be particle size (Kroeger et al., 2021) or the size of the pores (Yang et al., 2021). Therefore, in addition to obtaining lab analysis for different biochars, it is important to interpret lab results for a particular biochar in terms of identifying appropriate markets based on the strengths reflected in the characterization analysis. It may therefore also be useful to obtain additional characterizations outside of the current testing parameters required to meet IBI or EBC standards.

A recently emerging impetus for obtaining certification for biochar is related to the debut of biochar on two carbon removal marketplaces. Beginning in 2019, puro.earth accepted biochar as a carbon removal product category. In 2020, carbonfuture.earth was the second platform to validate and sell biochar-based carbon credits. Both marketplaces require biochar certification as well as C-sink certification.

It is beyond the scope of this paper to outline all of the different characteristics for all of the potential biochars, which could be generated from urban biomass. However, a brief description of the two most common types of biochars which can be derived from urban biomass may help to demonstrate the differences and potential end uses.

In the urban context, green waste consists of a variable blend of branches, grass, and leaves. This type of biomass could provide a large volume of feedstock for biochar production. The resulting biochar may, however, be quite variable as the blending rates of branches, grass, and leaves change seasonally. It is likely to have a higher nutrient content than wood alone but may contain heavy metals if treated wood gets mixed into the feedstock. When there is a significant fraction of grass or leaves it may have to be produced at relatively high temperatures in order for the H:C ratio to be .7 or below which is the threshold for a material to be considered as having long-term carbon persistence. One study found that the H:C ratio in green waste biochar produced at 400C versus 600C was reduced from .91 to .35 (Lopez-Cano et al., 2018), meaning that carbonizing green waste at low temperatures may not be sufficient to create a durable carbon sink. However, low temp green waste biochar has been shown to effectively immobilize lead, the most common heavy metal found in urban soils (Aslam et al., 2017). These are some of the trade-offs that urban carbon managers will need to understand and evaluate before deciding what type of biochar and end uses should be prioritized.

Sludge biochars are vastly different from biochar made from green waste. Sludge itself is quite variable depending on the types of waste streams processed at a wastewater treatment plant (WWTP) and whether the sludge is initially processed through an anaerobic digester. It may contain high nutrients (nitrogen, phosphorus) as well as contaminants such as heavy metals, pathogens, or micro-pollutants. TCC can remove pathogens and micro-pollutants but the heavy metals (e.g., iron) remain within the biochar structure in a more concentrated but largely immobile form. This often makes the biochar heavier than other types of biochar which can make application somewhat less dusty. In the US, several golf courses have indicated a preference for sludge chars for this reason in addition to the fact that it contains nutrients of value to growing greens. Iron-rich sludge biochar also has a propensity to absorb phosphorus (Wang et al., 2020), which can be useful in wastewater treatment plants or in cleaning up other types of effluents or waterways with excess phosphorus. This type of biochar can also be used as an adsorbent for heavy metals such as lead (Ho et al., 2017) and other contaminants (Gopinath et al., 2021).

Labs for characterization

Currently, the options for testing biochars to the IBI or European standards are quite limited. As the production of biochar increases, the number of labs willing to invest in the required testing equipment is expected to increase. Eurofins is the primary lab performing biochar characterizations in Europe. The situation in the United States is a bit more fragmented. Many labs are capable of performing a subset of the analysis related to the IBI standards but at this time, Control Labs in California is the only US laboratory that has a specific suite of tests that follow the tests and testing methodologies outlined by the IBI biochar certification standards. The US Biochar Initiative has been identifying and investigating other labs in the US that can provide various biochar testing and will be publishing this information on their website in the near future. One such example is the Natural Resource Research Institute (NRRI) at the University of Duluth. IBI and USBI are also reviewing current testing parameters and methodologies in an effort to ensure that testing is cost-effective and responsive to market needs.

Revenues & Costs Related to Bioenergy/Biochar Production

Business Models

An ever-increasing number of business models are evolving around the production and sale of bioenergy and biochar. Traditionally equipment has been purchased by biomass generators or waste managers and these plant managers become responsible for marketing all co-products. As there can be significant maintenance required on TCC equipment, leasing agreements are beginning to be offered which include equipment, service, and upgrades. Creating markets for biochar can be a daunting experience and some biomass generators are not well equipped or do not have the bandwidth to develop local or regional markets for their solid co-product. This has prompted some technology companies to develop business models that facilitate siting equipment where biomass is available, without burdening facility owners with adding unwanted responsibilities. In some cases, the technology developer retains ownership of the equipment while providing certain co-products to the biomass generator and retaining ownership of other co-products. As an example, V-Grid, a California company focusing on the dairy industry, provides lower-cost electricity to large dairy farms during peak hours and retains and markets the biochar for various uses. In other scenarios, technology vendors are developing off-take agreements with customers looking to reduce waste but not become biochar sellers. In the U.S. there are a growing number of biochar resellers who commit to long-term off-take agreements from a variety of different biochar producers and sell to end customers. Long-term purchases of carbon removal credits are now beginning to help with securing investment for expansion and new CHAB facilities.

Revenues

Depending on the technology and feedstock, various types of revenues can be generated from a CHAB plant including renewable energy, tipping fees, biochar, wood vinegar, pyro-oil, and most recently, carbon removal credits.

Energy

As previously mentioned, excess heat generated during carbonization has the potential to generate revenues or to offset the use of non-renewable energy needed for drying feedstock. Demand and thus revenues for heat used in district heating systems or to supply greenhouses can be quite seasonal as far less heat is needed in warmer months. The cost of current heat sources is variable, as is the amount of GHG emissions generated using different heat generation sources. Both of these factors can be motivators for cities to convert or adapt existing heating supply to technologies that convert urban organics into heat and biochar. Heating costs in Boulder, Minneapolis, Helsinki, and Stockholm spanned a range from 7 - 9 cents per kWh.

A growing number of carbonization technologies are capable of producing renewable electricity (e. Syncraft, All Power Labs). These systems make the most economic sense when the cost per kWh is high and the supply of biomass to generate electricity is consistent, with low moisture content, high BTU, and relatively low cost.

Tipping Fees

For certain types of waste, tipping or gate fees and/or landfill taxes are charged to dispose of the materials either in landfills, compost facilities, or incinerators. Tipping fees average $56 per ton in the US but in our survey were as high as $118/ton in Stockholm for digested sludge. Woody waste tipping fees are more nuanced with some contractors getting paid to bring chipped wood waste to biomass energy plants. In other situations, wood waste is chipped and blown into forested areas. However, in some cases fees are charged to the public or other entities to drop off urban or garden waste. Fees ranged from $22/ton in Stockholm to $120/ton in Helsinki. In some CHAB business models, tipping fees represent a significant part of their revenues, particularly for those converting sewage sludge. However, the quality and consistency of the biochar differs significantly and income from this particular biochar can be quite low.

Biochar

Perhaps the most commonly asked question of investors and entrepreneurs investigating biochar production facilities is ‘how much can I get per ton of biochar?’, followed closely by ‘who will buy my biochar?’. The price for biochar varies widely based on quality, consistency, demand, and end-market amongst other variables. Understanding the type of biochar that will be produced is a precursor to understanding what the best end markets are for the biochar and what materials biochar might be displacing which will also shed light on pricing. Due to a highly variable moisture content, biochar is most often sold by volume versus weight though pricing is still often discussed in terms of price per ton. Prices for biochar range widely ($200 - $2000 per ton) and are trending down as production increases. When certain kinds of post-processing are required either for reduced particle size or to activate the biochar in some way, prices are generally higher.

Carbon Credits

Revenue from carbon credits is a relatively new opportunity to improve the economics of combined energy and biochar production as mentioned previously. In mid-2021, less than two dozen biochar producers were certified to sell carbon credits on the three marketplaces that currently trade in carbon removals: Puro, carbonfuture, and First Climate. In 2021, it is anticipated that Verra (formerly known as Verified Carbon Standards or VCS), one of the world’s largest carbon registries, will also debut a biochar methodology. The Gold Standard and the American Carbon Registry are also rumored to be working on developing biochar GHG methodologies.

Demand for durable carbon removal credits has been rising quickly while supply is still relatively constrained and the two marketplaces that list biochar are start-ups. Sale prices for biochar credits on the Puro exchange range from 88 – 150€ per ton of CO2e which compares favorably to the other types of removal products listed on their platform, such as timber used in construction, cellulose insulation, which trade for 20 – 24€ per ton. The carbonfuture platform is currently focused solely on biochar credits which all sell for 100€ per ton of CO2e (excluding value-added tax). Their revenue model is set up to benefit all value chain members including the biochar producer, broker, and end-user. The revenue provided to this consortium varies depending on whether there are additional intermediaries but currently averages 62€.

As there are costs involved in becoming a listed seller, a minimum production volume of 500 tons per year is generally required to make the cost of biochar certification and listing on an exchange economically viable.

Converting the price per ton of CO2e back to income per dry ton of biochar depends on the carbon content in the biochar, GHG emissions during transport and production, and other factors outlined in the particular GHG methodologies used by the carbon marketplace. The Puro methodology is a more basic methodology, which does not require end-to-end tracking of the biochar, instead, relying on the producer to verify that the biochar was not sold to be used as fuel. The carbonfuture methodology is a more comprehensive, blockchain standard that factors in a conservative rate of decay depending on the particular end use of the biochar (e.g., in soils, animal feed, concrete, etc.). As a result, the carbon efficiency factor is lower for carbonfuture than for Puro but the verifiability is higher. A few examples will demonstrate how the revenues work from these marketplaces work:

Puro: Carbofex, the first biochar producer listed on the Puro exchange, has an embodied carbon index of 3.11 and trades for 100€. Assuming revenue to Carbofex is 66€ pt, the revenue per dry ton of biochar would be 205€ (US$243).

carbonfuture: Pacific Biochar, the first US biochar producer listed on the CF exchange averages 2.5 as the carbon efficiency index and receives 62€ pt, making the revenue per dry ton of biochar 155€.

Wood Vinegar, Pyro-Oil

Some TCC technologies generate liquid by-products in the form of wood vinegar (also called pyroligneous acid, liquid smoke, or wood acid) and pyrolysis-oil (also called bio-crude or bio-oil). Both of these products are as complex and variable as biochar. Refining these products and finding off-take agreements can be challenging but is starting to be looked at as additional revenue potential. In some cultures, particularly in Asia, wood vinegar is used in farming as an insecticide but must be heavily diluted. In concentrated form wood vinegar, which is highly acidic and contains hundreds of different constituents such as acetic acid, methanol, phenol, ester, acetals, ketone, formic acid, etc. can be considered hazardous and must be handled with and stored accordingly.

Pryo-oil also contains hundreds of different compounds including acids, alcohols, aldehydes, esters, ketones, phenols, guaiacols, syringols, sugars, furans, alkenes, aromatics, nitrogen compounds, and misc. oxygenates (Ringer *et al.,* 2006). Interest is growing in utilizing pyro-oil in some capacity as a renewable fuel. However, upgrading to higher-value fuels can be quite expensive. Pyro-oil can contain significant amounts of carbon (Ben *et al.,* 2019) which could potentially be sequestered in underground storage or in long-lived products such as asphalt. This is perhaps one reason why certain TCC technologies recirculate these liquids back into the pyrolysis system where they are eliminated. Unless plant developers have a sophisticated level of understanding about upgrading pyro-oil or until pyro-oil becomes a commonly tradable carbon sink, it may be best to de-emphasize the production of bio-oil in the short term.

Costs

Costs associated with installing bioenergy and biochar production can be substantial and variable. In addition to having the land and buildings needed to house the various different types of equipment and store co-products, other costs include labor, permitting, biochar analysis and certification, and potentially feedstock acquisition when no tipping fees are received.

The biomass and cost data provided by participating cities was mapped to three different types of TCC equipment that handle different types of feedstock and generate different co-products. This information is available upon request and estimates what the revenues and costs would be for carbonizing the quantity of biomass indicated by each city. The number of TCC units needed to convert each city's organic materials was estimated. However, only the Pyreg equipment is able to convert all types of biomass, so the number of units is larger than for the other two manufacturers.

Urban carbon managers can use this framework to model different types of equipment for different types of feedstock and customize data to fit their specific scenarios and update pricing as necessary (e.g. the price for c-sinks was conservatively estimated at 50 euros/USD when no internal price of carbon was supplied, the current rate for c-sinks is above 60€).

In most cases, the business case can be made for carbonization. Only in the case of Boulder did it appear that it would not be economical. However, this is likely due to a lack of information on certain costs (e.g., tipping fees).

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Bioenergy/Biochar production technologies – Current*

Company	HQ	Contact	Geography	Type	Feedstock	website	email
All Power Labs	USA	Alejandro Abalos	worldwide	Gasifier	woodchip	www.allpowerlabs.com	alejandro@allpowerlabs.com
Aries Clean Tech	USA	Joel Thornton	USA	Gasifier	wood, sludge	www.ariescleantech.com	Joel.Thornton@AriesCleanTech.com
ARTi Char	USA	Bernardo del Campo	worldwide	Mobile Retort	various	www.arti.com	bernidc@gmail.com
Biomacon	Germany	Tomas Hoffman	Europe, India	Pyrolysis	various	www.Biomacon.de	th@biomacon.com
Biomass Controls	USA	Jeff Hollowell	worldwide	Pyrolysis	various	www.biomasscontrols.com	jeff@biomasscontrols.com
Biomass Energy Techniques	USA	Joel Toth	N America	Pyrolysis & Gasification	wood, hemp	www.biomassenergytechniques.com	joelt@biomassenergytechniques.com
Carbofex OY	Finland	Sampo Turkeinen	Europe	Pyrolysis	woodchip	www.carbofex.fi	
Carbon Technik Shuster	Germany	Nabil Linke	Germany	Pyrolysis	pellets	www.ct-schuster.de	n.linke@carbex.one
ICM	USA	Bert Bennett	Americas	Updraft Gasifier	wood	www.icminc.com	Albert.Bennett@ICMINC.com
Organilock	USA	Scott Laskowski	USA	Furnace	woodchip	www.organilock.com	scott@organilock.com
Polytechnik	Austria	Viktor Radic	Europe	Retort: batch	woodchip	www.biomass.polytechnik.com/en/	v.radic@polytechnik.at
Pyreg	Germany	Helmut Gerber	worldwide	Pyrolysis	wood, sludge	www.pyreg.com	h.gerber@pyreg.de
Pyrocal	Australia	James Joyce	worldwide	Furnace	various	www.pyrolcal.com.au	james.joyce@pyrocal.com.au
Scandi Energy	Norway	Toralf Ekelund	Europe, Africa	Gasifier	wood, MSW	www.scandienergy.no	tek@scandienergy.no
Syncraft	Austria	Marcel Huber	Europe, Japan	Gasifier; floating fixed b	woodchip	www.syncraft.at	marcel.huber@syncraft.at
TrollWorks	USA	Gordon West	USA	Pyrolysis	various	www.troll.works	gorwest4@gmail.com
VOW (Scanship + Etia)	Norway	Nataliia Kaisen	worldwide	Pyrolysis	various	www.vowasa.com	nataliia.kasian@scanship.no

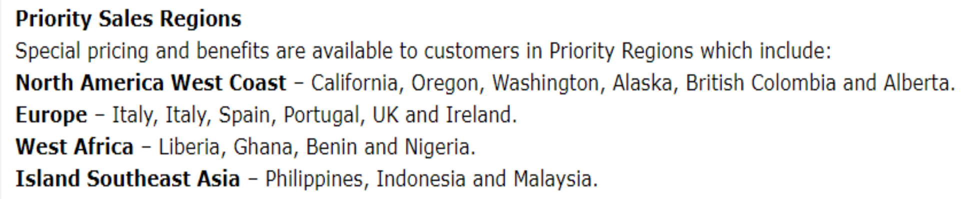
*Technologies included in this list currently have at least one plant operating in Europe or the US using urban feedstocks. Listing a technology is not an endorsement.

ALL POWER LABS
Carbon Negative Power & Products

ON-DEMAND, AFFORDABLE, CARBON-NEGATIVE ENERGY

Biomass/Bioenergy Technology:

- Power Pallet 30:
    - 25 kW - electrical capacity
    - 50 kWth - heat capacity
    - 5% biomass to biochar conversion rate
    - System conversion 1 kg biomass : 1 kWh electricity : 2 kWth heat : 0.05 kg biochar
    - Version 2.01 released. This is the same system shipped to Stonybrook a couple months ago.
- 50 kW Power Pallet 30 system:
    - Twice capacity of Power Pallet 30 system
    - Same conversion rates
    - Pilot release with first system to be installed at UC Hopland Research and Extension Center
- CharTainer:
    - Combined Heat and Biochar Unit
    - 250 kg/hr capacity
    - 500 kWth - heat capacity
    - 15% - 20% biomass to biochar conversion rate
    - System conversion 1 kg biomass : 2 kWth heat : 0.15 - 0.20 kg biochar
    - Pilot version to be installed at Anderson Biomass Complex end of 2021



Priority Sales Regions

Special pricing and benefits are available to customers in Priority Regions which include:

North America West Coast – California, Oregon, Washington, Alaska, British Colombia and Alberta.

Europe – Italy, Italy, Spain, Portugal, UK and Ireland.

West Africa – Liberia, Ghana, Benin and Nigeria.

Island Southeast Asia – Philippines, Indonesia and Malaysia.

http://www.allpowerlabs.com/

ARIES CLEAN TECHNOLOGIES™

ACE DDLF-2000 Downdraft gasifier

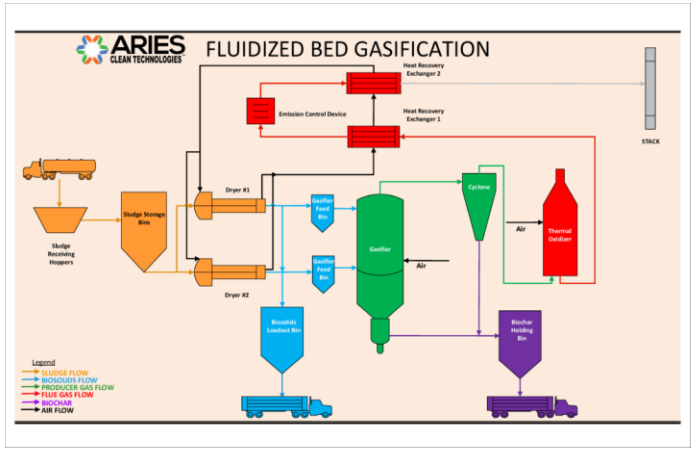
Lebanon, Tennessee. Commissioned October 2016

- 32 biomass/day (~25% moisture)
  - Waste wood – pallets is primary feedstock
- 3 T biochar/day; 1,000T/year (<10% moisture)
  - Carbon content >90%
  - **3,500 t/yr CO2 capture & storage**
- 420 kW electricity
  - offsets electrical usage at wastewater treatment plant nearby

•**Waste:** More than 16 million pounds diverted from landfills each year

•**Energy:** More than 36 MW-hrs generated over the 20 year life of the project

•**Emissions:** More than 5,000 pounds of carbon emissions averted annually



Linden NJ Project Snapshot

- State of the art, patented fluidized bed facility located in a re-purposed building within the Linden Roselle Sewerage Authority complex
- Process 430 tons per day of biosolids
- Producing 22 tons of biochar per day
- Closed-loop system requires no fossil fuels during operations
- Full operations in Q2 2021

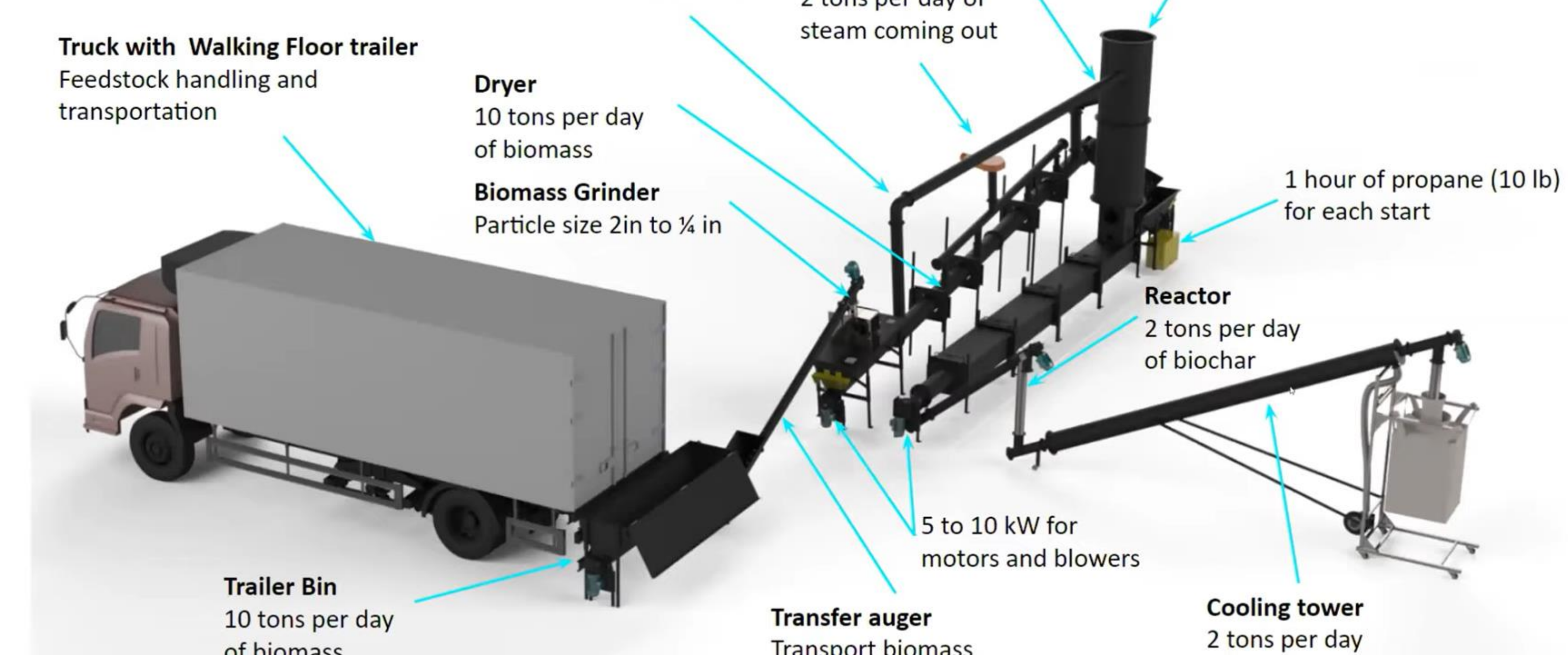
Local Benefits

- Diverts 130,000 tons of biosolids from landfills annually
- Lowest cost option for biosolids disposal in NY/NJ Metropolitan area
- System is carbon negative and captures methane that would otherwise be released into the atmosphere
- Reduce transportation related GHGs
- Aries' Build-Own-Operate model provides no financial risk to Linden Roselle Sewerage Authority
- Serving the largest metropolitan area in the US

https://ariescleantech.com/

Mobile pyrolysis systems

Component Description


Recirculated flue gases going into dryer

Combustion gases coming out

Recirculated flue gases cold after the dryer

2 tons per day of steam coming out

Truck with Walking Floor trailer
Feedstock handling and transportation

Dryer
10 tons per day of biomass

Biomass Grinder
Particle size 2in to ¼ in

1 hour of propane (10 lb) for each start

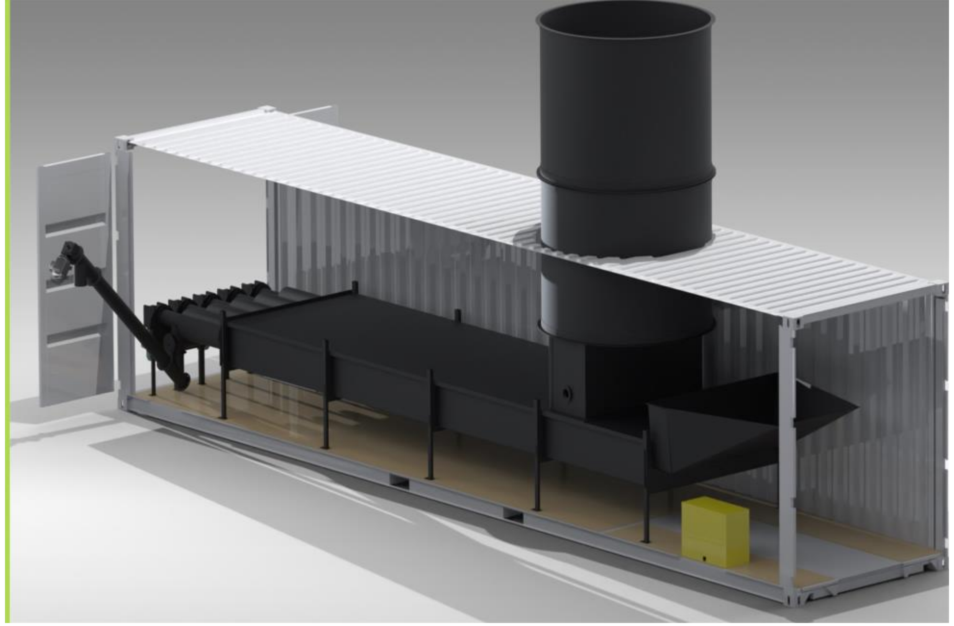
Reactor
2 tons per day of biochar

5 to 10 kW for motors and blowers

Trailer Bin
10 tons per day of biomass

Transfer auger
Transport biomass

Cooling tower
2 tons per day



5 train system
- 50 ton wet/day in
- ~40 ton of dry in
- 10 ton of Biochar out).

www.arti.com/

BIOMACON

DECARBO Energy Systems

FARM

Larger heat loads up to 160kW.

Used on **agricultural** and **municipal holdings**, by **foresters** or in **greenhouses**.

INDUSTRY

Large heat loads up to 400kW.

Suitable for **sewage treatment plants**, **industrial operations** and **manufacturing processes** or **heat contractor**.

- Range of sizes
  - 40 – 500 kW thermal output
- 22% biochar yield (up to 500tpy)
- Maximum 30% moisture content
- Plants throughout Europe and one in India
- Most plant operators receiving carbon credits

https://www.biomacon.com/?lang=en

A Scalable and Replicable Solution

Biomass Controls provides scalable, decentralized refineries to rapidly recover nutrients and treat for green resources including: manure, food waste, textiles, and excreta.

Red Dog, Alaska, USA

Woodstock, Connecticut, USA

Warangal, Telangana, India

BIOMASS CONTROLS PBC

BIOMASS ENERGY
TECHNIQUES INC

Primary system is a gasification system that can produce up to 10% biochar by weight. Typically these are set up with boilers to supply heat to buildings; however, a variety of heating options are available.

The BET 24-PRD (Pyrolysis Rotary Drum) system (PRD Concept document) uses BET 24-S as the primary system to produce thermal energy to the drum. The material in the drum flows toward the primary system, entering through the afterburner (oxidizer) and exits at the primary system. The gases produced from the material as it travels through the drum are combusted in the afterburner and we can use the heat from the afterburner stack to heat an off heat boiler or direct the hot where needed.

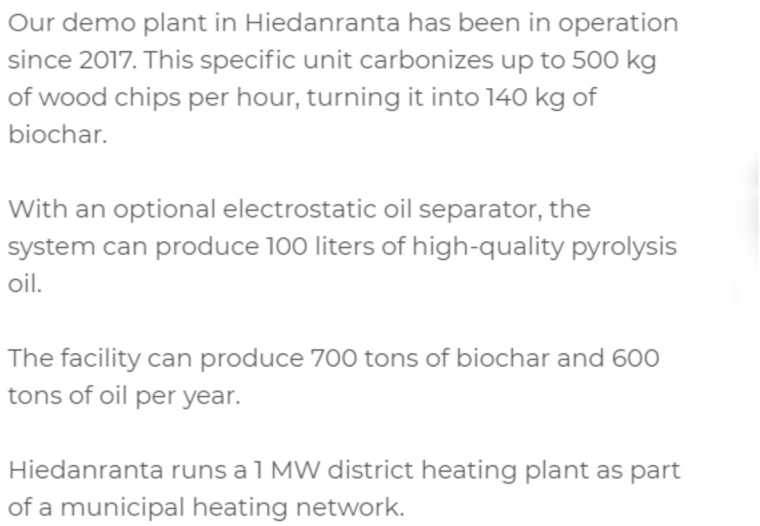
Operates best on feedstocks with a moisture content of 25-65%

Hemp

Wood chips

https://biomassenergytechniques.com/

CARBOFEX

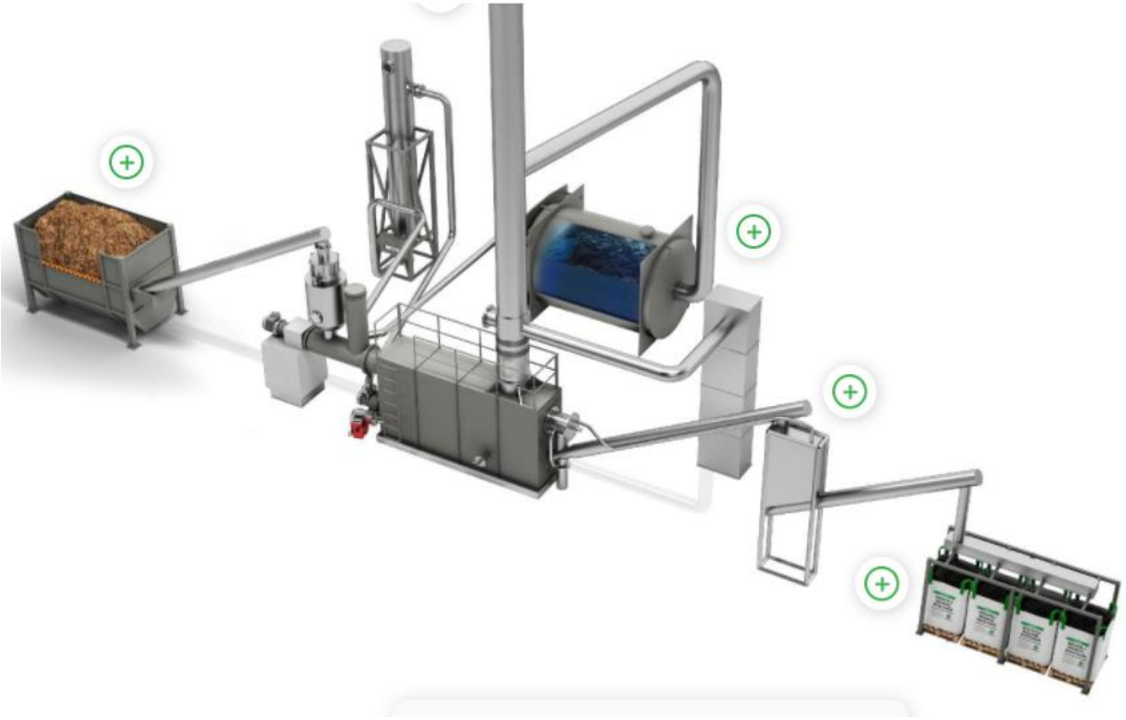


Our demo plant in Hiedanranta has been in operation since 2017. This specific unit carbonizes up to 500 kg of wood chips per hour, turning it into 140 kg of biochar.

With an optional electrostatic oil separator, the system can produce 100 liters of high-quality pyrolysis oil.

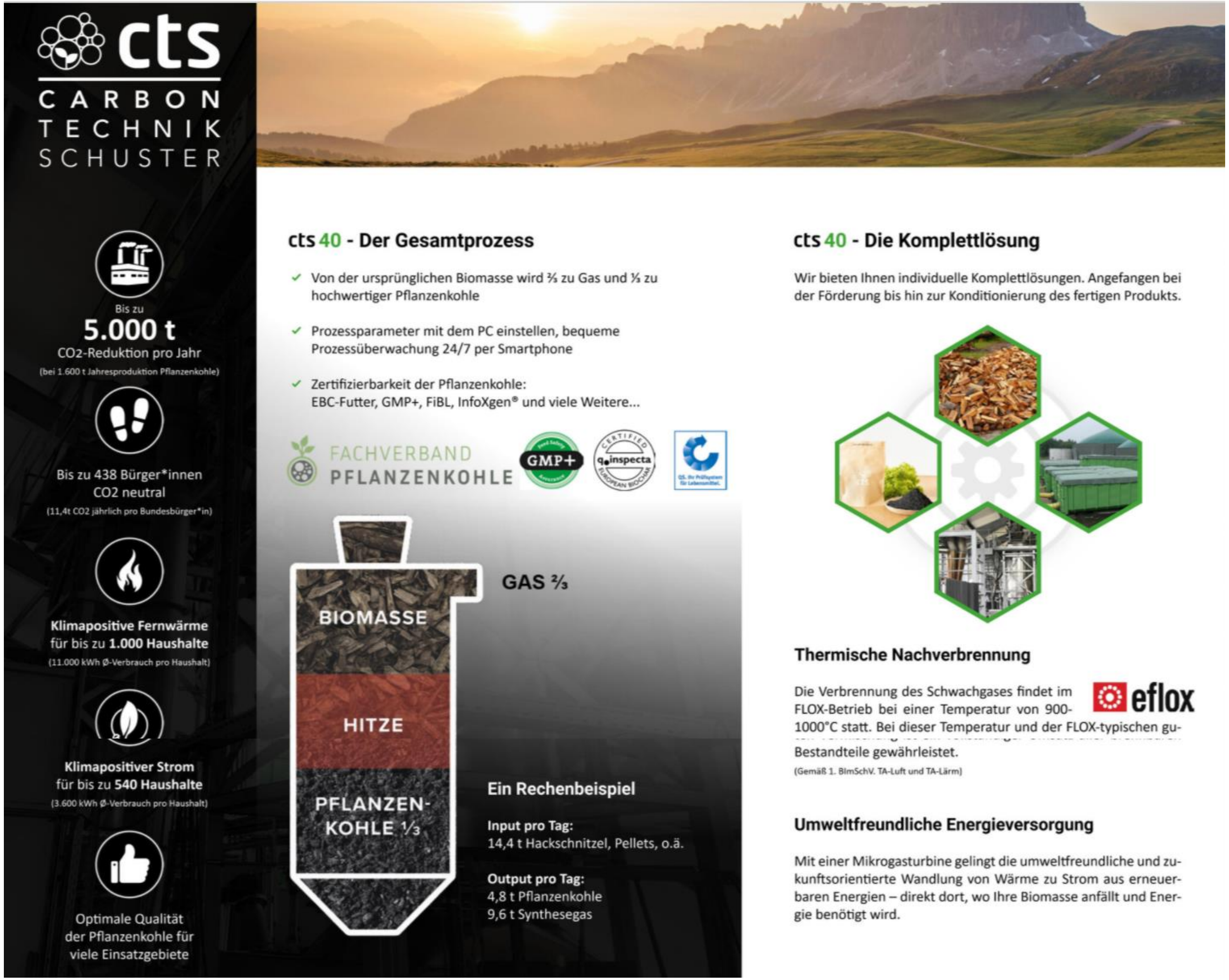
The facility can produce 700 tons of biochar and 600 tons of oil per year.

Hiedanranta runs a 1 MW district heating plant as part of a municipal heating network.



First producer to receive carbon removal credits!

www.Carbofex.fi



cts
CARBON
TECHNIK
SCHUSTER

Bis zu
5.000 t
CO2-Reduktion pro Jahr
(bei 1.600 t Jahresproduktion Pflanzenkohle)

Bis zu 438 Bürger*innen
CO2 neutral
(11,4t CO2 jährlich pro Bundesbürger*in)

Klimapositive Fernwärme
für bis zu **1.000 Haushalte**
(11.000 kWh Ø-Verbrauch pro Haushalt)

Klimapositiver Strom
für bis zu **540 Haushalte**
(3.600 kWh Ø-Verbrauch pro Haushalt)

Optimale Qualität
der Pflanzenkohle für
viele Einsatzgebiete

cts 40 - Der Gesamtprozess

- ✓ Von der ursprünglichen Biomasse wird ⅔ zu Gas und ⅓ zu hochwertiger Pflanzenkohle
- ✓ Prozessparameter mit dem PC einstellen, bequeme Prozessüberwachung 24/7 per Smartphone
- ✓ Zertifizierbarkeit der Pflanzenkohle: EBC-Futter, GMP+, FiBL, InfoXgen® und viele Weitere...

Ein Rechenbeispiel

Input pro Tag:
14,4 t Hackschnitzel, Pellets, o.ä.

Output pro Tag:
4,8 t Pflanzenkohle
9,6 t Synthesegas

cts 40 - Die Komplettlösung

Wir bieten Ihnen individuelle Komplettlösungen. Angefangen bei der Förderung bis hin zur Konditionierung des fertigen Produkts.

Thermische Nachverbrennung

Die Verbrennung des Schwachgases findet im FLOX-Betrieb bei einer Temperatur von 900-1000°C statt. Bei dieser Temperatur und der FLOX-typischen gu- [illegible] Bestandteile gewährleistet.

(Gemäß 1. BImSchV. TA-Luft und TA-Lärm)

Umweltfreundliche Energieversorgung

Mit einer Mikrogasturbine gelingt die umweltfreundliche und zukunftsorientierte Wandlung von Wärme zu Strom aus erneuerbaren Energien – direkt dort, wo Ihre Biomasse anfällt und Energie benötigt wird.

Annual output for cts40

- 1,600 tons of biochar
- 5,000 CO2e reduction
- 2,000MWh electricity
- 11,000 MWh heat
- 2 – 5 ROI

- Variable temp 400 – 900
- No moving parts in the carbonization zone
- Pilot plant has been operation for 2 years making 800tpy high quality biochar
- First production plant will be in Damstadt, Germany
- 4 - 5 additional plants to open in next 18 months

ICM's GASIFICATION SYSTEMS and BIOCHAR PRODUCTION TECHNOLOGY

- **Model 75, 150 and 300 Gasifiers**
  - From 75 to 300 mTon/day
  - Dual M-300 installed in Kansas
- **Biochar & Char Production**
  - From 10 to 80+ mTon/day
    - Biochars to agriculture, etc.
    - RDF sourced char/carbon to landfill

- **Combined Heat & Power**
  - From 75 to 600 mTon/day input
  - 3 to 20+ MW*e* Power Generation
  - 6 to 50+ MW*th* Heating
  - Integration with Industrial and Municipal Processes

- **Robust Design**
- **Small Footprint**
- **Medium- to Large-Scale Applications**
- **Controllable Char Carbon Content**
- **Low Energy, Air-Blown Gasification**
  - < 25 kW per M-300 (gasifier only)
- **Tested Feedstocks**
  - Wood Chips
  - Ag. Residuals
  - Perennial Grasses
  - C&D and RDFs
  - Blend Fuels …
    - Wood + Biosolids
    - RDF + Biosolids
    - RDF + Tire Chips

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the **energy** of innovation™

www.icminc.com

ORGANILOCK

Innovative Biomass Solutions

- BioBurner BB1000, BB500, BB300
- Multi-fuel biomass hot water heating
  - Preferred feedstock: woodchips, sawdust, pellets
- US only currently

https://organilock.com

POLYTECHNIK
Biomass Energy

Pyrolysis Plant
Green Carbon Plant Germany

POLYTECHNIK
Biomass Energy

GreenCarbon

Industrial scale
demonstration plant
3,000 t/a
operates continuously
since 2016

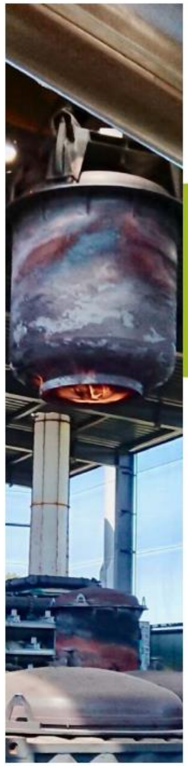
First automated and controlled retort
plant worldwide

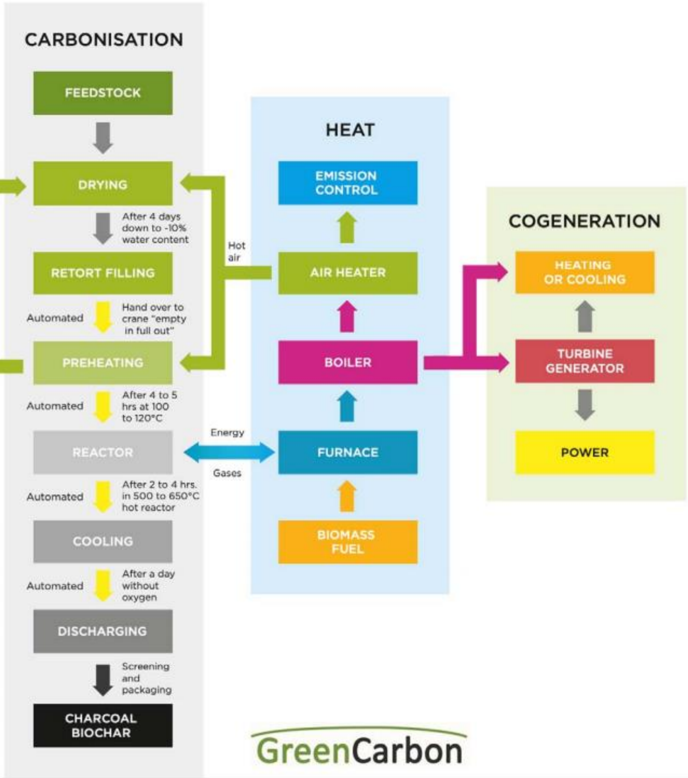
Environmentally-friendly
with lowest possible emissions

Removal of over 10,000 t CO_2
per annum
from the atmosphere

Pyrolysis Plant
Carbon Negative Co- and Tri-Generation

POLYTECHNIK
Biomass Energy





CARBONISATION
FEEDSTOCK
DRYING
After 4 days down to -10% water content
RETORT FILLING
Automated
Hand over to crane "empty in full out"
PREHEATING
Automated
After 4 to 5 hrs at 100 to 120°C
REACTOR
Automated
After 2 to 4 hrs. in 500 to 650°C hot reactor
COOLING
Automated
After a day without oxygen
DISCHARGING
Screening and packaging
CHARCOAL BIOCHAR

Hot air
Energy
Gases

HEAT
EMISSION CONTROL
AIR HEATER
BOILER
FURNACE
BIOMASS FUEL

COGENERATION
HEATING OR COOLING
TURBINE GENERATOR
POWER

GreenCarbon

		3,000	4,500	6,000	9,000	12,000
Tonnes of biochar (dry)	[t/a]	3,000	4,500	6,000	9,000	12,000
Power generation*)	[kWe]	500	750	1,000	1,350	1,900
Heat for heating/cooling*)	[kW]	860	1,290	1,720	2,600	3,400

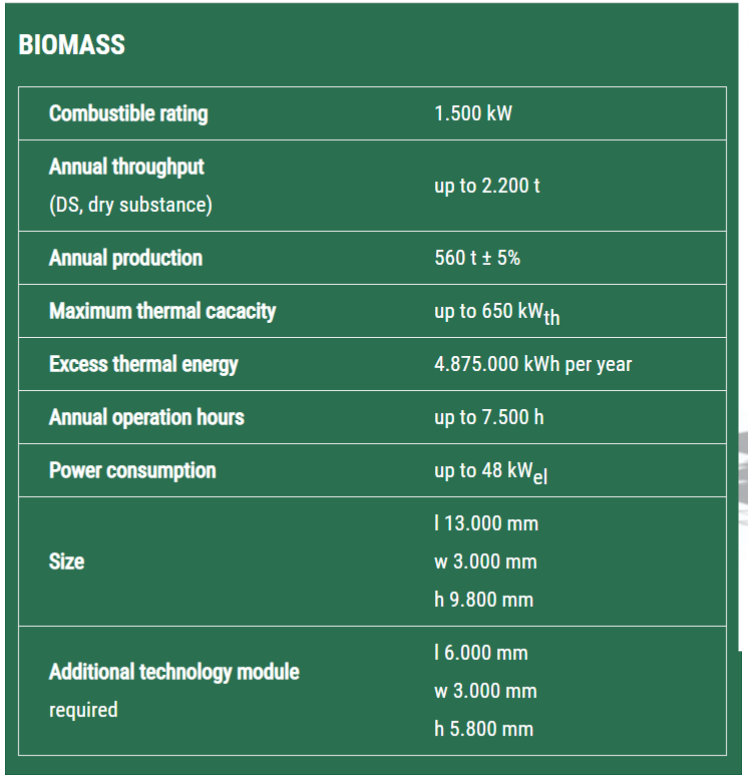
*) Tailored to customer requirements

https://biomass.polytechnik.com/en/

PYREG

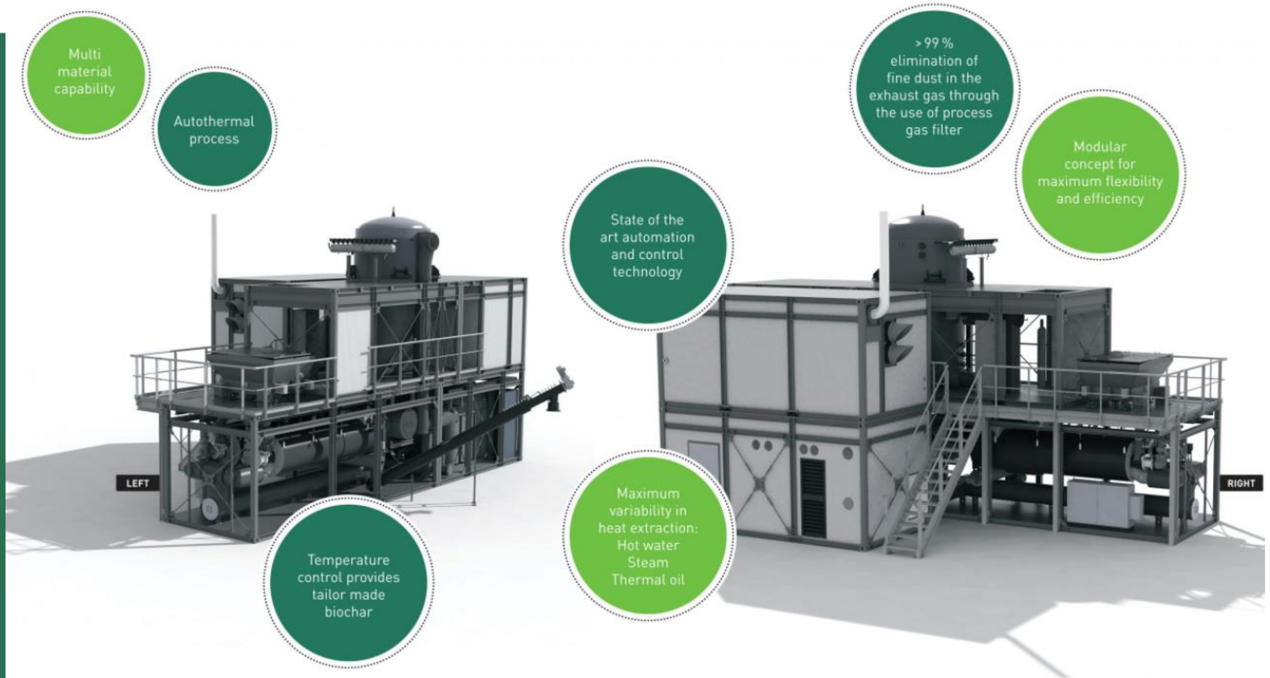
CARBON TECHNOLOGY
SOLUTIONS

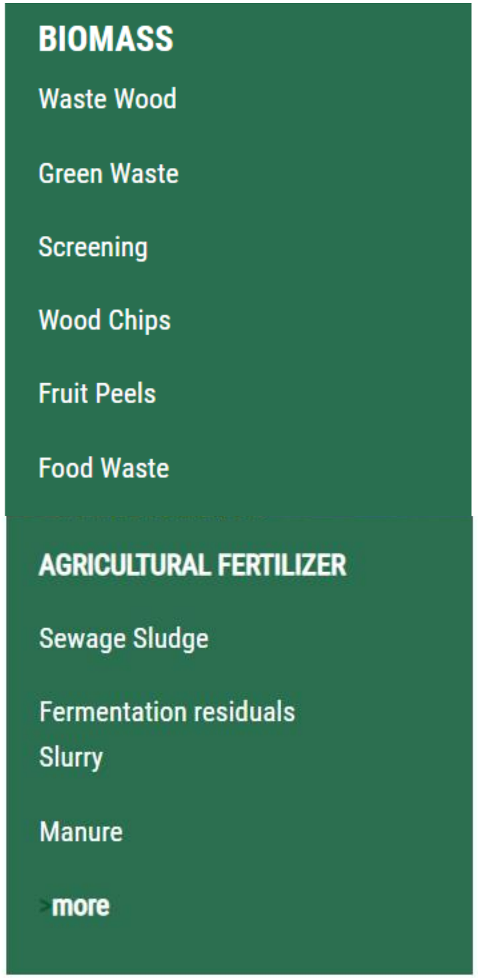
SYSTEM DATA



BIOMASS

Combustible rating	1.500 kW
Annual throughput (DS, dry substance)	up to 2.200 t
Annual production	560 t ± 5%
Maximum thermal cacacity	up to 650 kW_{th}
Excess thermal energy	4.875.000 kWh per year
Annual operation hours	up to 7.500 h
Power consumption	up to 48 kW_{el}
Size	l 13.000 mm w 3.000 mm h 9.800 mm
Additional technology module required	l 6.000 mm w 3.000 mm h 5.800 mm





BIOMASS

- Waste Wood
- Green Waste
- Screening
- Wood Chips
- Fruit Peels
- Food Waste

AGRICULTURAL FERTILIZER

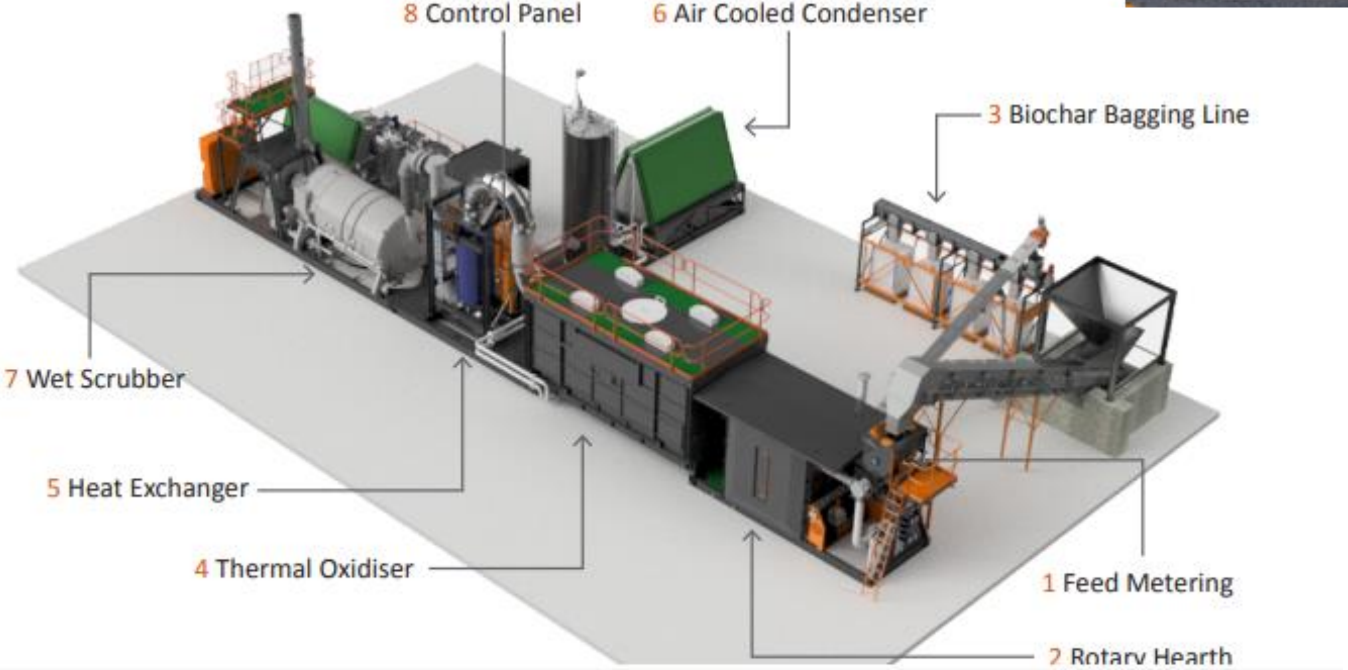
- Sewage Sludge
- Fermentation residuals
- Slurry
- Manure

› more

https://pyreg.com/

PYROCAL

Continuous Carbonization Technology (CCT)



www.pyrocal.com.au

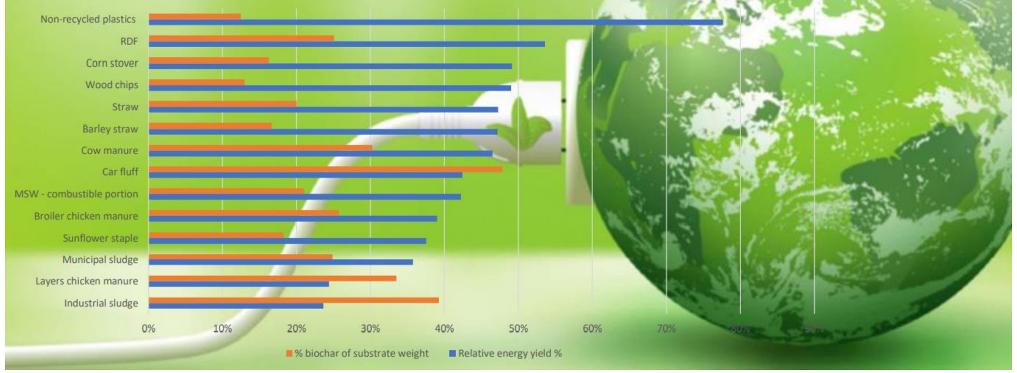
SCANDI Energy

Turn any solid waste stream into a 20+ year revenue stream.
Typically 3-7 years payback time depending on your feedstock.
Modules of 5 to 100 metric tonnes per day.

- No limit with respect to feedstock [1]
- Unrivalled robustness & versatility
- Easy to operate & maintain
- Inherent carbon capture
- End of waste

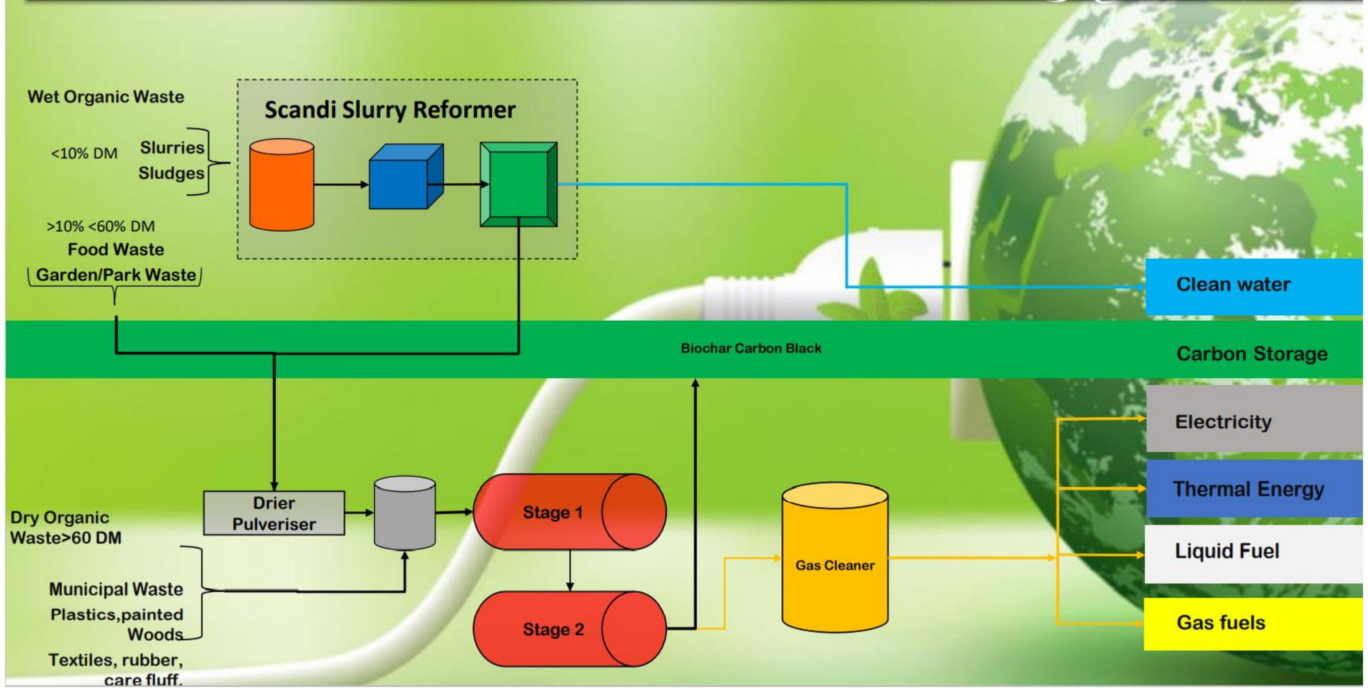
- **Norwegian technology**
- **First system delivered to Egypt in 2020 & will convert MSW into energy & biochar to be used to fertilize desert soils.**
- **Four additional systems being implemented in Turkey.**
- **Pilot plant being built in Norway (to open by Fall 2021)**

Energy yield versus biochar yield for different substrates



Scandi Slurry Reformer SSR & Scandi Vacuum Gasifier-SVG

VACUUMGASIFIER



Wet Organic Waste

<10% DM Slurries Sludges

>10% <60% DM Food Waste Garden/Park Waste

Scandi Slurry Reformer

Dry Organic Waste>60 DM

Municipal Waste

Plastics,painted Woods

Textiles, rubber, care fluff.

Drier Pulveriser

Stage 1

Stage 2

Gas Cleaner

Biochar Carbon Black

Clean water

Carbon Storage

Electricity

Thermal Energy

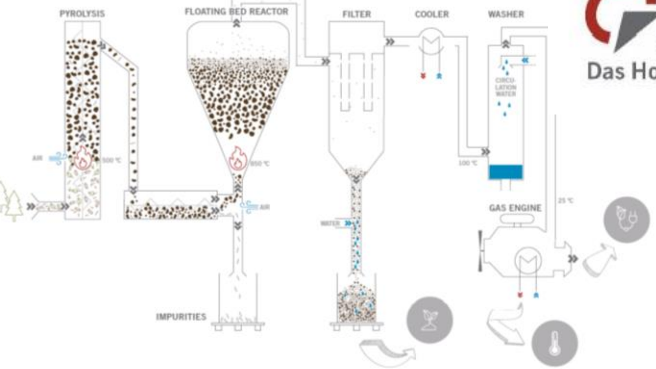
Liquid Fuel

Gas fuels

www.scandienergy.no

CW700-200+:
Dornbirn / AT

2015
250kW
600t/a -CO2



SYNCRAFT®
Das Holzkraftwerk.

CW1800x2-1000:
Laas / IT

2018
1.000kW
1.800t/a -CO2

CW1000-300:
Innsbruck / AT

2017
300kW
600t/a -CO2

CraftWERK 1000-300
Innsbruck / Austria

261 kW	electric power
892 kW	thermal power
½ ton+	biochar/day **

Total operating hours of plant: more than 15,000 hours in 2 years. The plant in Innsbruck has an increased power output.

** ~ 600 t CO2 per year

CW1800-500:
Dornbirn / AT

2019
500kW
900t/a -CO2

CW1200-400:
Ternitz / AT

2020
400kW
700t/a -CO2

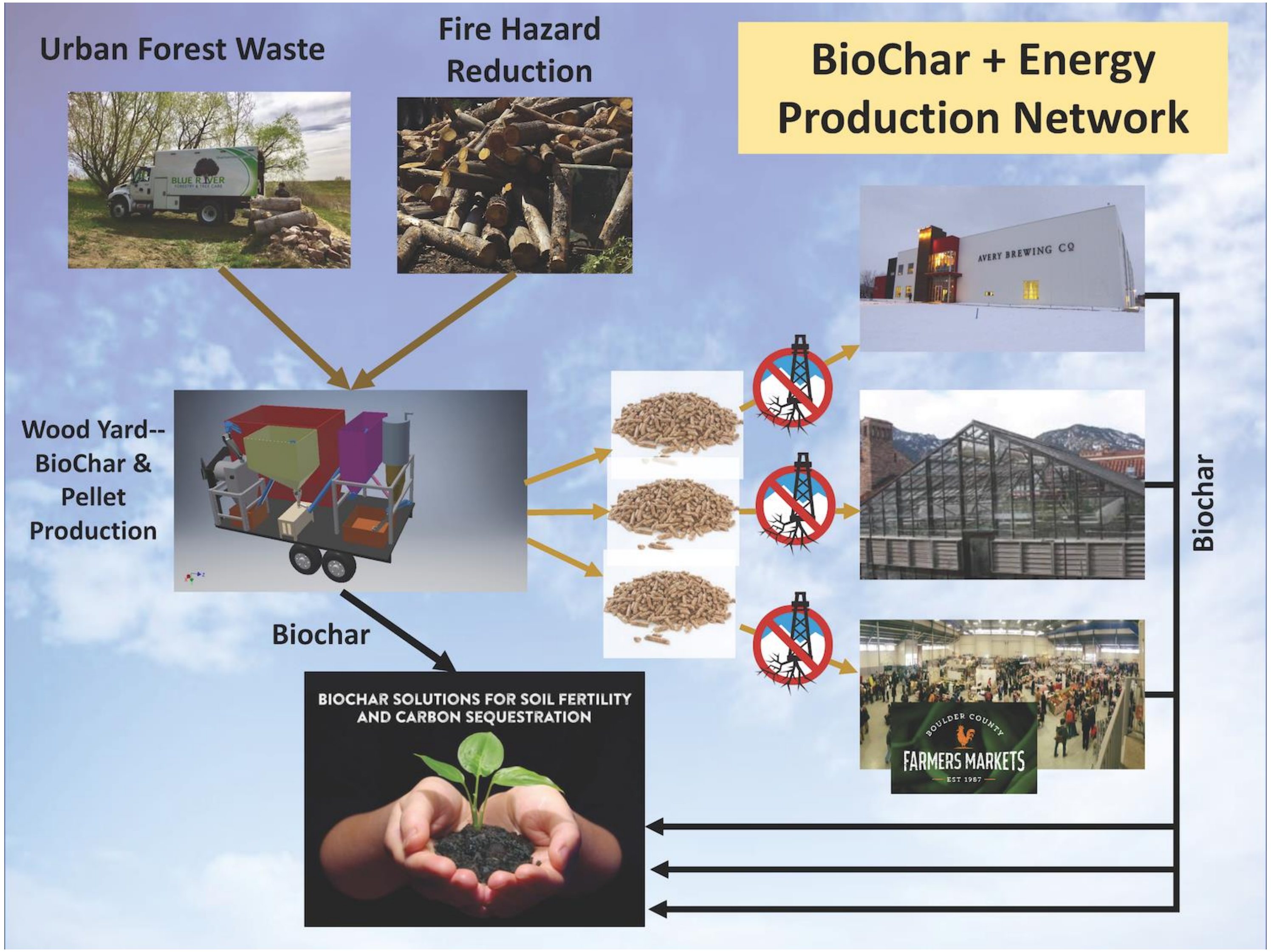
CW1800-500 x4:
Shingu / JP

2020
1.800kW
3.200t/a -CO2

CW1800-500:
Osijek / HR

2020
500kW
900t/a -CO2

TROLLWORKS



BioChar + Energy Production Network

Urban Forest Waste

Fire Hazard Reduction

Wood Yard-- BioChar & Pellet Production

Biochar

BIOCHAR SOLUTIONS FOR SOIL FERTILITY AND CARBON SEQUESTRATION

Biochar

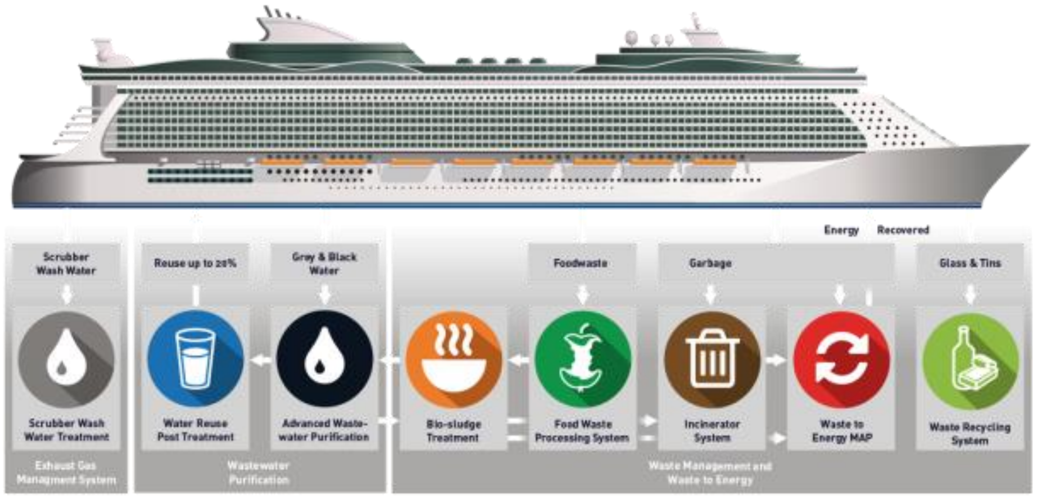
www.troll.works

VOW

Including subsidiaries Scanship & Etia’s BioGreen pyrolysis technolgy

SCANSHIP

for cleaner oceans



Awaiting info from company

Bioenergy/Biochar production technologies – Emerging*

Technology Overview - Emerging

Company	**HQ**	**Contact**	**website**	**Comments**
Advanced Resilient Tech	USA	Marshall Mermell	www.art.co.im	
Aqua Green	Denmark	in permitting	www.aquagreen.dk	sludge
BioGreen Woods	Portugal	Sergio Silva	www.biogreenwoods.eu	slow pyrolysis
Bio-techfar	Canada	Paul Franch	www.bio-techfar.com	mechanical fluidized bed py
Caribou Biofuels	USA	Kieran Mitchell	www.cariboubiofuels.com	gasifier - fuels focus
CarboCulture	USA			Fast pyrolysis
Char Technologies	Canada	Andrew Friedenthal	www.chartechnologies.com	high temperture pyrolysis
JM	China	Ag & wood	(no website)	pyrolysis - seeking regional
International BioRefinerie	USA	Raj Kuthuria	(no website)	fast pyrolysis
Mavitec	NL	Hendrik Hijlkema	www.mavitecgreenenergy.com	gasifier - manures
Rainbow Bee Eater/ECHC	Australia	Peter Burgess	www.rainbowbeeeater.com.au	pyrolysis - greenhouses
SF Biochar	USA	Taryn Draxler	www.sfbiochar.com	biochar, wood vinegar,
Simeken	Canada	Rod Pare	www.simekeninc.com	
WoodCo Eneergy	Ireland			
V-grid energy	USA	Greg Campbell	www.vgridenergy.com	Gasification

*Technologies included in the emerging list may not yet be operating in Europe or the US or they may be focusing on non-urban feedstocks.