IBI White Paper:
Pyrolysis and Gasification of Biosolids to Produce Biochar
June 2013

Introduction

The need to dispose of human-generated waste streams is growing in line with the expansion of urban population centers. This is particularly true for the byproducts of wastewater treatment. According to the US EPA, there are over 7 million dry tons of biosolids (stabilized sewage sludge) produced per year in the US. In 2004, 49% of biosolids were beneficially used—primarily for agricultural land application—with most of the remainder either landfilled or incinerated (NEBRA 2007). Because biosolids have a high nutrient content, land application as a fertilizer substitute is an appealing management strategy. Yet concerns around nutrient run-off and contamination of waterways have led to tighter environmental controls making land application increasingly tenuous. Promising alternate management strategies exist but are in early stages of development. Pyrolysis and gasification—a continuum of thermochemical conversion processes—have been shown to minimize harmful air emissions, while producing energy and biochar, a carbon-rich solid material with beneficial soil health properties. This white paper briefly explores experiences of pyrolysis and gasification of biosolids as a waste management strategy, and research into biosolids biochar (BSB) as a soil amendment.

Biochar background

Biochar is a solid, carbon-rich material obtained from the thermochemical decomposition of biomass in an oxygen-limited environment. Biochar is essentially charcoal produced for agricultural purposes, which exhibits certain physicochemical characteristics agreed upon by international biochar experts (see the *IBI Biochar Standards* available at www.biochar-international.org/characterizationstandard). Biochar's unique physicochemical properties and soil health benefits were first observed scientifically in soils in the Amazon basin that have been enriched with charcoal by pre-Columbian Amerindian populations—so-called *terra preta* (dark earth) soils. Since initial investigations of *terra preta* beginning in the 1990s and early 2000s, in recent years there has been a surge of research into biochar as a soil amendment for agricultural purposes. This is reflected in the number of peer-reviewed scientific publications on biochar as documented in the International Biochar Initiative's (IBI) biochar bibliography; published papers per annum increased from 65 in 2008 to 272 in 2012 and are set to surpass 300 in 2013 with 147 to date as of June 2013.

Chief among biochar's interesting properties is its resistance to biological and physical degradation when incorporated into soils, thus conferring other properties (e.g., nutrient and water retention, microbial activation, liming, and others) that improve soil functions over time periods from decades to centuries. Any biomass can theoretically serve as a feedstock (source material) for biochar production. Currently, the vast majority of biochar research and commercial projects utilize woody biomass and agricultural residues, yet dewatered biosolids are a suitable feedstock for biochar production. Because of the known presence of heavy metals and organic pollutants in biosolids, care must be taken during thermochemical conversion to avoid harmful air emissions as well as the accumulation of these toxicants in the final biochar material. To address concerns around presence of toxicants in biochar, the *IBI Biochar Standards* referenced above require testing for heavy metals, PAHs, PCBs and dioxins/furans.

Technologies for producing biosolids biochar

While the technology for incinerating (burning) biosolids is well-established, pyrolysis and gasification technologies for processing biosolids are in much earlier stages of RD&D (with the exception of a few examples in Japan and Germany discussed below). Pyrolysis and gasification, in contrast to incineration, eliminate and restrict oxygen flow, respectively, to thermally decompose the biosolids into their liquid, gaseous and solid fractions. Energy recovery can occur either by capturing the process heat or containing and refining the synthesis gas (syngas) and/or bio-oil for later utilization.

In June 2012, EPA released a Technology Assessment Report titled "Aqueous Sludge Gasification Technologies" that provides detailed background on the state of this technology and presents profiles of selected pilot and commercial-scale projects currently in operation.

Biosolids gasification in the US

In the US, there are only a few examples of biosolids gasification and pyrolysis projects, all of which focus efforts on the generation of heat or electric energy. In Sanford, FL Maxwest Environmental Systems installed a fixed bed updraft gasifier that is capable of drying and processing 80 tons per day of wet biosolids. Installation of this type and size of system currently ranges from $7-10M (Winkler 2012) but over the 20 year lifespan of the Sanford project the city is expected to save $13M by offsetting natural gas purchases (EPA 2012).

In Stamford, CT the public water control agency used US Department of Energy (DOE) funds to build a pilot gasification system to process class A biosolids and generate syngas for energy production. Although the pilot phase was successful, funding was not secured to build the commercial scale facility commissioned by the company Nexterra (EPA 2012). With both the Sanford and Stamford systems, it is unclear if the solid byproducts exhibit any properties of biochar.

While there is a dearth of active projects in the US, there is a recognition that biosolids can serve as an energy source to offset energy needs at waste treatment facilities, especially as land application becomes more costly and restricted. For example, the Bay Area Biosolids to Energy (see http://bayareabiosolids.com/home) project is a coalition of 19 San Francisco Bay Area water quality agencies seeking to develop joint renewable energy technologies. The prospect of additional revenue streams from biochar byproducts of these technologies can help the bottom line of such projects.

International experiences with pyrolysis and gasification of biosolids

Japan has a centuries-old tradition of producing charcoal from woody biomass for use in energy production as well as agriculture. More recently, Japan has begun to experiment with the large-scale pyrolysis of biosolids to produce a carbonized biosolid for co-firing with coal in thermo-electric generation plants. In Hiroshima and Tokyo, plants were recently completed that are able to pyrolyze up to 27,800 and 109,000 tons per year (tpy) of dewatered sludge, respectively, into biosolids biochar (Asia Biomass Office; Oda 2007). Primary drivers for these projects are utilization of the thermal content of the biosolids as well as greenhouse gas (GHG) emission reductions (pyrolysis virtually eliminates the generation of N_2O—a potent GHG released during sewage sludge incineration) from the wastewater treatment sector. For example, the Tokyo project is expected to reduce GHG emissions by 37,000 tpy CO_2e over the baseline incineration scenario.

Germany has several pilot- and full-scale biosolids gasifiers in operation. All of these systems are relatively small, processing on the order of 1-5 tons per day and generating 12-69 kW of net electric power. More detailed information on the experiences in Japan and Germany are given in the EPA Technology Assessment Report.

Agronomic research with BSB

Given the relatively long experience with production of BSB in Japan, researchers there have investigated various aspects of its agronomic properties. Kawano et al. (2012) found that, especially on infertile sandy soils, BSB increased plant growth using begonia as a test species. Yachigo and Sato (2013) report varying effects on spinach plant growth and soil responses to two BSBs, with variability mostly dependent on biochar process temperature (low out-performed high) and soil quality. However, in a separate study common beans growing in soils considered to be fertile showed a positive response to BSB application (Teranuma and Mori, 2002). Clearly there is more work to be done to parse out specific properties of individual BSBs and match those to appropriate cropping impacts and scenarios.

As with untreated biosolids, BSB can potentially contain high concentrations of heavy metals and organic pollutants. Kawano et al (2012) found that BSB produced at 800C had high levels of P but also of Cu, Zn, Cd, and Ni. Other studies (e.g. Werle and Wilk 2010) reach similar conclusions. Care must be taken during the thermochemical conversion process as well as the utilization and land application of BSB to avoid environmental contamination and adverse human health effects. One way to provide assurances on product safety is to test BSBs for toxicants according to the criteria set forth in the *IBI Biochar Standards*.

Biosolids biochar in the Chesapeake Bay watershed

Pyrolysis and gasification are emerging technologies to manage biosolids. Both processes capture the latent energy content in biosolids and produce biochar, a potentially useful soil amendment for agriculture and land remediation. This is clearly fertile grounds for increased public and private investment and research. A project in the Chesapeake Bay watershed could highlight a trifecta of benefits. For example, novel disposal methods for biosolids (especially crucial as Bay states ratchet down on land application of biosolids), renewable energy production, and cropping benefits in areas known to have poor soils such as the Delmarva Peninsula.

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