"Biochar may represent the single most important initiative for humanity's environmental future. The biochar approach provides a uniquely powerful solution, for it allows us to address food security, the fuel crisis, and the climate problem, and all in an immensely practical manner. " Prof. Tim Flannery, 2007 Australian of the Year

NASTY TO NICE

FROM BIO-WASTE TO ENERGY, FUEL, BIOCHAR AND CARBON SEQUESTRATION

The Terralogix Group, LLC (Terralogix) has created a system to convert some of the most biologically problematic waste streams to energy and valuable products, and to foster a potential agricultural revolution, greatly reduce nutrient inputs to aquatic systems, and sequester current-day carbon while doing so. The system is based upon pyrolysis, or anaerobic combustion, of bio-wastes, including manure, municipal sludge, paper mill sludge, and any other biologically produced waste material. The pyrolysis reaction produces energy and fuels for electricity generation, as well as biochar, a potent soil catalyst and a form of permanent carbon storage once incorporated into soils.

What follows are descriptions of the pyrolysis process and its products, the Terralogix pyrolysis and electrical generation system, and the anticipated outcome following deployment of the Terralogix system. We have also included a discussion of biochar's effect in soils when used as an amendment.

Pyrolysis Process and Products

Pyrolysis is a self-maintaining, exothermic process, using heat and gasses produced by the reacting biomass itself to sustain the pyrolysis reactions. It is also a carbon-negative process, taking up and sequestering carbon captured from the present-day atmosphere during the growth of plants for food and fuel.

Pyrolysis is fueled by various forms of biomass, including animal manure, sewage sludge, plant wastes, wood, etcetera. The pyrolysis process is (by definition) conducted in the absence of gaseous oxygen, turning biologically-produced wastes into a carbon matrix, plus usable fuels including liquid "bio-oils," plus syngas (synthesis gas), plus heat. The ratio of biochar to bio-oil production is regulated by the heat of the process – low (relatively) temperature or slow pyrolysis yields more biochar, higher temperatures (or fast pyrolysis) yield more syngas.

Pyrolysis offers a useful and potentially profitable means of disposal of otherwise difficult and highly polluting animal byproducts, including municipal sludge and wastes from Confined Animal Feed Operations (CAFOs). Other biochar fuels, or feedstocks, can be any form of bio-waste, including field residues (e.g. grass seed crop residues routinely burned in Oregon's Willamette Valley), dead animals (diseased and otherwise deceased chickens from large poultry operations on Maryland's Eastern Shore), or forestry and sawmill byproducts and wastes.

It is important to note that pyrolysis of animal wastes, including sewage sludge, destroys pathogens as well as most pharmaceuticals during the high temperature pyrolysis process.

Syngas: Syngas (also known as synthesis gas) is a mixture of hydrogen, carbon monoxide (a flammable gas), methane, some CO_2 and low percentages of other constituents. It has approximately half the energy content of natural gas, and can either be refined to concentrate its energy content or be further processed to generate industrial gases, fertilizers, chemicals, fuels and other products. In the Terralogix system, syngas is used as a fuel for generation of electricity.

Bio-oil: The bio-oil from pyrolysis of biologically derived materials is composed of a blend of hydrocarbons and aromatics. It has less energy density than does fossil diesel, but can be used directly as a fuel in applications similar to those using heating oil or by turbine generators. Its use reduces emissions of CO_2, SO_2, chlorite and sulfur. It is competitive in cost compared to natural gas and diesel, is easy to store and to transport, and is a valuable source of chemicals to replace petrochemicals in the manufacture of plastics and other products.

Heat: A large amount of heat is released during pyrolysis. This heat is used to generate electricity using steam turbines and/or heat engines. Excess heat can also be used to heat buildings including, for instance, buildings housing such Confined Animal Feed Operations as poultry farm buildings. A particularly creative use of post-generator heat is to heat year-round lagoons for the culture of oil-producing algae, such that not only is no heat released into any receiving waters or the atmosphere, but the energy is captured by plant growth for conversion to fuels as well as additional biomass to be cycled back through the pyrolizer.

Biochar: The abbreviated and paraphrased Wikipedia definition of Biochar is as follows:

> “**Biochar** is a form of charcoal created by pyrolysis of biomass, and is comprised of a stable solid rich in carbon content…”

Biochar is generated through pyrolysis, the anaerobic combustion process. It differs from charcoal produced through aerobic, low-temperature combustion by the complexity of its molecular forms as well as by the incorporation of oxidized forms of nitrogen, phosphorus and sulfur, converted to nitrates, phosphates and sulphates and bound within the newly formed carbon matrix. Binding of N, P, and S and carbonates prevents leaching of these nutrients/pollutants into surface and ground waters.

Production of biochar is significant to reducing carbon loading to the Earth’s atmosphere. Production of biochar in closed pyrolysis systems releases little CO_2 into the atmosphere, and this fraction is a component of the synthesis gas. Carbon removed from today’s atmosphere through absorption and processing of carbon by living organisms is thereby sequestered within the solid carbon matrix, which is itself extraordinarily valuable as a very long-lived soil amendment, where it acts essentially as a bio-catalyst. This is a long-term sequestering of carbon – biochar is shown to be stable for millennia in even highly active soils.

Effects of Biochar in Soils: Biochar is porous and sterile – it has an extremely large amount of surface area (up to 400 m^2 per gram), due to the voids left behind as differentially volatile material is converted to gas. These voids and the char itself retain soil moisture and are hospitable to soil organisms, particularly fungi. Soil microbes, including fungi, are instrumental in translating the mineral fraction of the soil into forms that become available to plants, considerably reducing the need for fertilizer inputs. In fact, these microbes, when in the presence of biochar, increase their ability to process and cycle nitrogen, a key component for plant growth. The addition of biochar to soils not only increases access by plants to nutrients, it also increases the ability of plants to withstand drought conditions. And biochar is instrumental in the improvement of soils having difficult textural characteristics – clays due to lightening the soil matrix and providing nutrient pathways, and sands by increasing the ability of the soil to retain moisture as well as providing a more biologically effective growth medium. Two dozen studies commission by the United Nations show that inclusion of biochar into soils improved crop production from 20% to 220%.

From the International Biochar Initiative (IBI): *"Biochar enhances soils. By converting agricultural waste into a powerful soil enhancer that holds carbon and makes soils more fertile, we can boost food security, discourage deforestation and preserve cropland diversity. Research is now confirming benefits that include:*

- *Reduced leaching of nitrogen into ground water*
- *Possible reduced emissions of nitrous oxide*
- *Increased cation-exchange capacity resulting in improved soil fertility*
- *Moderating of soil acidity*
- *Increased water retention*
- *Increased number of beneficial soil microbes*

Biochar can improve almost any soil. Areas with low rainfall or nutrient-poor soils will most likely see the largest impact from addition of biochar."

There are literally thousands of peer-reviewed papers available on the effect of biochar in soils, the consensus of which is that biochar improves essentially every function of soils pertaining to plant growth, from moisture retention to nutrient cycling, retention and availability, soil tilth and other beneficial effects. And one of the most important facts about biochar in soils is that it simply remains there! And it does so for millennia, maintaining its soil improvement function into perpetuity.

The Terralogix System

The Terralogix Group pyrolysis and electrical generation system starts with preparation of the feedstock to be pyrolized. This focuses on two factors: bringing the moisture content to 20% or less and, as necessary, pelletizing the material for even and predictable processing. Following feedstock preparation, the material is fed continuously into the pyrolizer, which is itself computer and operator monitored and controlled.

As pyrolysis continues, the various products materialize. Some of these, including the bio-oil and the biochar, are collected to undergo further processing and refinement. Depending upon the feedstock, the biochar may emerge as a fine powder and as such would be difficult and unpleasant to handle. Finely textured biochar is therefore pelletized prior to being packaged for distribution to its various markets. The bio-oil is placed in containers and either shipped for use as is or taken elsewhere for refinement into a diesel fuel usable in vehicles and other diesel powered machinery. The syngas is polished, if necessary, then routed to the generator. The pyrolysis-derived heat is used to create steam for a turbine generator or processed through a heart engine, which then powers a generator. The heat may also be utilized to heat buildings or water.

As noted above, electricity can be generated using both fuel and heat. And the system can be managed to create different balances of products. For instance, if it is desired to produce almost all syngas for electrical generation and correspondingly little bio-oil and biochar, the system is run hot, up to 1,000^{o} C. If more oil and char are desired, the system is run at 400 – 500^{o} C. The balance of products is predicated upon the needs of the client as well as in response to whatever markets exist at any given time.

System Scales

Terralogix pyrolysis/generation systems are available at different scales. The smallest system is based on a mobile truck-mounted pyrolysis unit capable of processing 100 to 500 pounds of feedstock per hour and, paired with an appropriately sized electrical generator, can generate up to approximately 250 kilowatts of electricity per hour. The intermediate system is trailer-mounted (or barge-mounted) and can handle two to four tons per hour, feeding a generator capable of generating up to four megawatts of power. The largest system is stationary and can be very large indeed. It can take in 10 tons of feedstock or more per hour, enabling generation of at least 10 megawatts of electricity.

Bio-waste Disposal Opportunities:

Generation and sale of the products and byproducts described above are not the primary focus of this paper – rather, it is the intake element of the biochar production process that offers potentially the highest and most dynamic social, environmental and economic opportunities.

Wastewater Treatment Plant Sludge: Currently, the wastes from many thousands of sewage treatment plants are being collected and either burned, producing pollutants and yielding a relatively small amount of energy, or land-applied, or dumped at sea, or placed in landfills. Having a collector come to pick up sewage sludge is expensive, and what’s being done with it is not only a waste of a highly energetic raw material but is generally highly polluting and does nothing to sequester carbon or generate any other significant corollary value.

Confined Animal Feed Operations: CAFOs have a serious manure problem. And the waste from CAFOs is not only extremely energetic, it’s also fairly easy to deal with – there are virtually no extraneous elements such as unwanted trash or other flushed debris. Regulatory definitions of CAFOs are included in the EPA’s CAFO Final Rule of 2008, which also specifies that CAFOs must file Notices of Intent seeking coverage under the EPA’s National Pollution

Discharge Elimination System (NPDES) general permit if discharges of manure will occur. This includes land applications of manure as well as other discharges to Waters of the US. Provision of manure to biochar production plants or location of a pyrolysis plant at the CAFO site enables the CAFO operator to certify to the EPA that no discharges of manure will occur to either land or water. And no discharges means no requirement for a permit, and no need to pay for expensive manure disposal methodologies, find land for land-application of manure, or nutrient management plans, or monitoring of discharges, or payments of fines for accidental or otherwise improper discharges.

The Regulatory Mandate: Therefore, in consideration of business opportunity, it is worth noting that the pyrolytic conversion of animal wastes and human sludge satisfies a broad set of regulatory requirements. Not only are sewage treatment plants required to remove accumulated sludge periodically, but the disposal of the sludge must meet certain stringent requirements. CAFOs can avoid expensive sequences of manure management and reporting requirements through certification of "no discharge."

Bio-waste Disposal Costs and Mandates:

There is, to say the least, a lot of biological waste material to dispose of, and it costs a vast amount to deal with it using current disposal methods. For instance, a November 2008 report by the New Hampshire Commission to Study Methods and Costs of Sewage, Sludge and Septage Disposal (HB 699, Chapter 253, Laws of 2007) states that in 2007, the state of New Hampshire generated 97,600 wet tons of sewage sludge (roughly equivalent to 7,600 tons of sludge feedstock for pyrolysis). Disposal costs were approximately $75 per wet ton for a total of somewhat over $7 million. This is an example of a direct cost to municipalities.

Disposal costs are also indirect. A Sept. 6, 2007 report from the Association of Metropolitan Water Agencies states: "Dairy cows in CAFOs upstream from Lake Waco created 5.7 million pounds of manure per day that was over-applied to land and made its way into the lake. The state found that nearly 90% of the controllable phosphorus in the river came from CAFOs in the watershed, and an independent researcher who conducted much of the state's analysis found that dairy waste applied to fields supplied up to 44% of the lake's phosphorus. From 1995 to 2005, the city spent $3.5 million on phosphorus-related water pollution, and has spent a total of approximately $70 million to improve water treatment. To recoup costs the city filed suit against 14 large industrial dairies in 2003 and eventually reached a settlement with the defendants."

EPA rules promulgated in 2003 and 2008 require that land application of manure from CAFOs be metered per comprehensive nutrient management plans. As a result, there are limits to the quantities of manure that can be land-applied per area of land, and land available for land application of manure has, in most regions of the country, become scarce. CAFO operators are therefore compelled to ship manure farther and farther from its source, competing with other operators who are similarly seeking opportunities for land application. Further, it has become clear that soils and vegetation are not able to absorb as much of the nutrient loading as was previously believed. And further yet, phosphorus, typically the limiting nutrient in aquatic systems, accumulates in soils over time such that heavy runoff events deliver devastating phosphorus loads to receiving water bodies.

The costliness of bio-waste disposal - in combination with the collateral damage generated by improper/incomplete disposal of bio-wastes - in combination with the regulatory (and social) mandate for full and documented bio-waste management – in combination with the growing market for carbon credits - in combination with the benefits and salable products yielded by the pyrolysis process offers a full set of excellent reasons for municipalities and CAFO operators to consider this new approach to bio-waste disposal.

Potential Returns

It is impossible to exactly determine the returns from deployment of a Terralogix pyrolysis/generation system, in that markets for some of the materials yielded by the system are relatively undeveloped. Further, some of the benefits can be indirect. For instance, if the system is deployed by a government, it is reasonable to expect that removal of nutrients from field-applied sludge contaminating jurisdictional waters could be considered a public benefit. Similarly, when the use of biochar in agriculture generates increased crop yields, reduces nutrient inputs to surface and ground waters, reduces fertilizer use and therefore costs, and sequesters carbon, these can be counted as both indirect social benefits and direct benefits to the farming community.

Below we offer an estimate of some of the tangible and direct benefits derived from the operation of the small mobile system for ten hours per day:

Electricity: 250 kilowatts per hour x 10 hours = 2.5 megawatts per day
2.5 megawatts per day @ $.0949 per kilowatt hour: $237

Bio-oil: 50 kg per hour x 10 hours per day = 500 kg
500 kg bio-oil ÷ 1.2 kg/liter = 417 liters ÷ 3.8 liters/gallon = 110 gallons
110 gallons x (assumed) $2.50 per gallon: $275

Biochar: 100 kg biochar per hour x 10 hours/day = 1,000 kg or 1.1 tons biochar

(The actual price of biochar is in flux. High-quality biochar from chicken litter has been selling for $600 per ton – we don't believe that is a realistic or stable price, despite its proven benefits, especially as more of it is produced and it must be steadily removed from the source. Here, we assume a price of $200 per ton.)

1.1 tons x $200 per ton: $220

Tipping fees: 250 kg sludge x 10 hours per day = 2.5 MT sludge x 1.1 tons/MT = 2.75 tons
2.75 tons x $52 per ton:.. $143

Total/day: $875

This total does not consider a variety of factors possibly impinging on the actual returns including, for instance, the cost of trucking sludge to a disposal site, or a more retail distribution of biochar (e.g. bagged in 40 lb bags and sold at garden centers). It also assumes a certain mix of products, continuous operation of the facility, and successful access to markets for the products.

It does not include any income from carbon credits/offsets, though these can be sold. And it is clear that larger units will enjoy economies of scale – pyrolizing twenty times the volume of sludge does not require a machine having twenty times the cost.

Conclusion

The Terralogix pyrolysis/electrical generation system offers an innovative, clean and cost-reducing approach to management of bio-wastes, including municipal sludge and CAFO manure. Although implementation of the Terralogix system is in the pilot project stage, each component of the system is well known and amply proven, and there are no real obstacles to full deployment other than the unfamiliarity of the approach to potential customers.

The Terralogix system is compelling because it solves so very many problems. It disposes of bio-wastes with little or no emissions, it destroys waste-borne pathogens and pharmaceuticals, it generates energy in several forms, it prevents influx of pollution to surface and ground waters, it satisfies a number of regulatory mandates, it is carbon-negative, it considerably reduces the need for fertilizers and thereby reduces fertilizer runoff, and it returns agriculture to being carbon-based, versus being based upon sterile soil with inputs of commercial nitrogen, phosphorus and potassium. The system generates income, creates jobs and reduces the need for trucking large volumes of unpleasant and heavy material.

In short, this is a win, win, win technology. We believe that initial deployment of the Terralogix system will prove cost effective and popular, and that once its financial, social and environmental benefits are known, its use will become wide-spread and routine.