Presentation at USBI2016, Corvallis, OR

NextChar Characterization Matrix

Measuring biochar properties to establish Valuation

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valuation

1. the act of estimating or setting the value of something

The premise:

Somewhere, somehow, some device or combination of conditions converted some biomass into **a porous solid that belongs to the broad class of materials called "Biochar".**

One can measure properties of said biochar, and one would like to relate those properties to both:

- **The conditions under which the biochar was created, and**

- The impact said biochar might reasonably be expected to impart in potential applications for the material, specifically applications that **someone might be inclined to pay for the biochar**

- This might be called **"A Method to the Madness ……."**

Principal Constituents of Biochar:

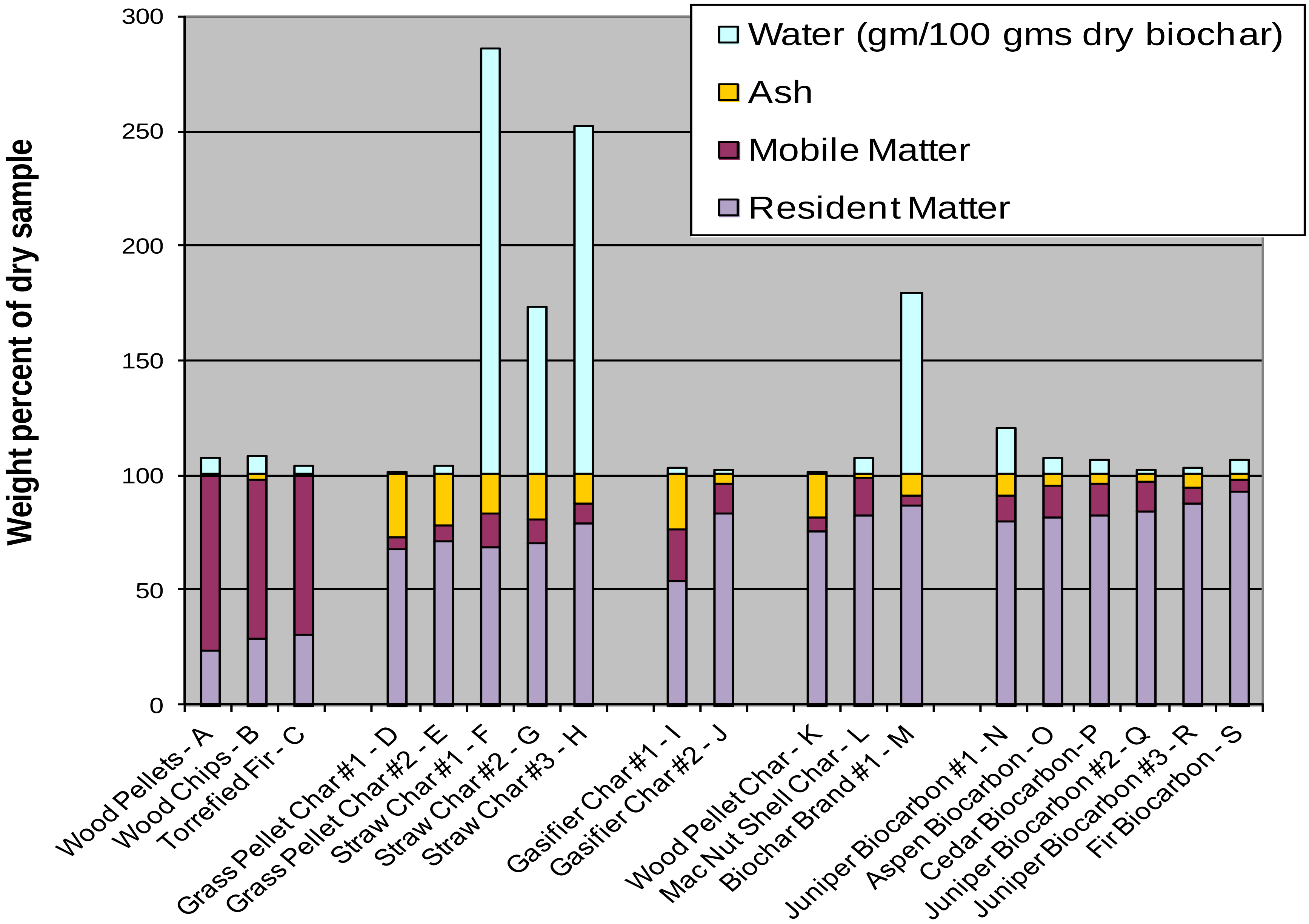
- **Moisture (as delivered)**
  - Moisture is not a bad thing, but it is not worth paying for ……
  - Moisture is added after char production, usually to cool or passivate the char
  - Moisture in the bag does not mean the char will have superior moisture retention in soil – it means moisture was added …

Principal Constituents of Biochar:

- **Ash (as delivered and from what)**
  - Converting Biomass to Char removes the moisture and much of the organic portion, but very little of the ash constituents – they accumulate to 3 to 4 times of the level present in the dry pre-carbonization biomass
  - Soluble Ash is the principal pH effect of biochar addition to soils – can act like lime
  - Ash includes Nitrogen? – depends on test
  - **Biochar does not convey plant nitrogen – but it facilitates nitrogen-fixing microbes**

Principal Constituents of Biochar:

- Moisture (as delivered)
- Ash (as delivered and from what)
- **Mobile Matter versus Resident Matter**
  - Mobile - can migrate out of the char
  - Resident - stays with the char & soil
  - Matter = Carbon and H&O portions
  - Carbon is measured for CO_2 sequestration, but plants care about soluble organics and plant nutrients available in the soil


Weight percent of dry sample
300
250
200
150
100
50
0
Water (gm/100 gms dry biochar)
Ash
Mobile Matter
Resident Matter
Wood Pellets - A
Wood Chips - B
Torrefied Fir - C
Grass Pellet Char #1 - D
Grass Pellet Char #2 - E
Straw Char #1 - F
Straw Char #2 - G
Straw Char #3 - H
Gasifier Char #1 - I
Gasifier Char #2 - J
Wood Pellet Char - K
Mac Nut Shell Char - L
Biochar Brand #1 - M
Juniper Biocarbon #1 - N
Aspen Biocarbon - O
Cedar Biocarbon - P
Juniper Biocarbon #2 - Q
Juniper Biocarbon #3 - R
Fir Biocarbon - S

Principal Constituents of Biochar:

- Moisture (as delivered)
- Ash Content (as delivered and from what)
- Mobile Matter versus Resident Matter

- **Cation Exchange Capacity**
  - **ion exchange resin-like behavior**

- **Adsorption Capacity**
  - **activated carbon (adsorption) behavior**

Pivotal Biochar properties:

Short-term Effects are due primarily to

- **Ash Content** – due to pH impact
- **Mobile Matter** – as a carbon source for soil microbes, which will compete for available nitrogen
- Mobile matter, if "sugar", can jump-start soil biology

Long-term Effects are attributed to **only** the

- **Resident Matter** – because it
    - ***Adds Volume with high porosity to the soil***
    - ***Increases Cation Exchange Capacity***
    - ***Introduces significant Adsorption Capacity***

The whole is equal to the sum of the parts;

- +/- the synergisms (called non-linearities), or
- unless there is some force of nature activated by the combination of two or more parts (rare),
- or you believe in magic (which I don’t…)

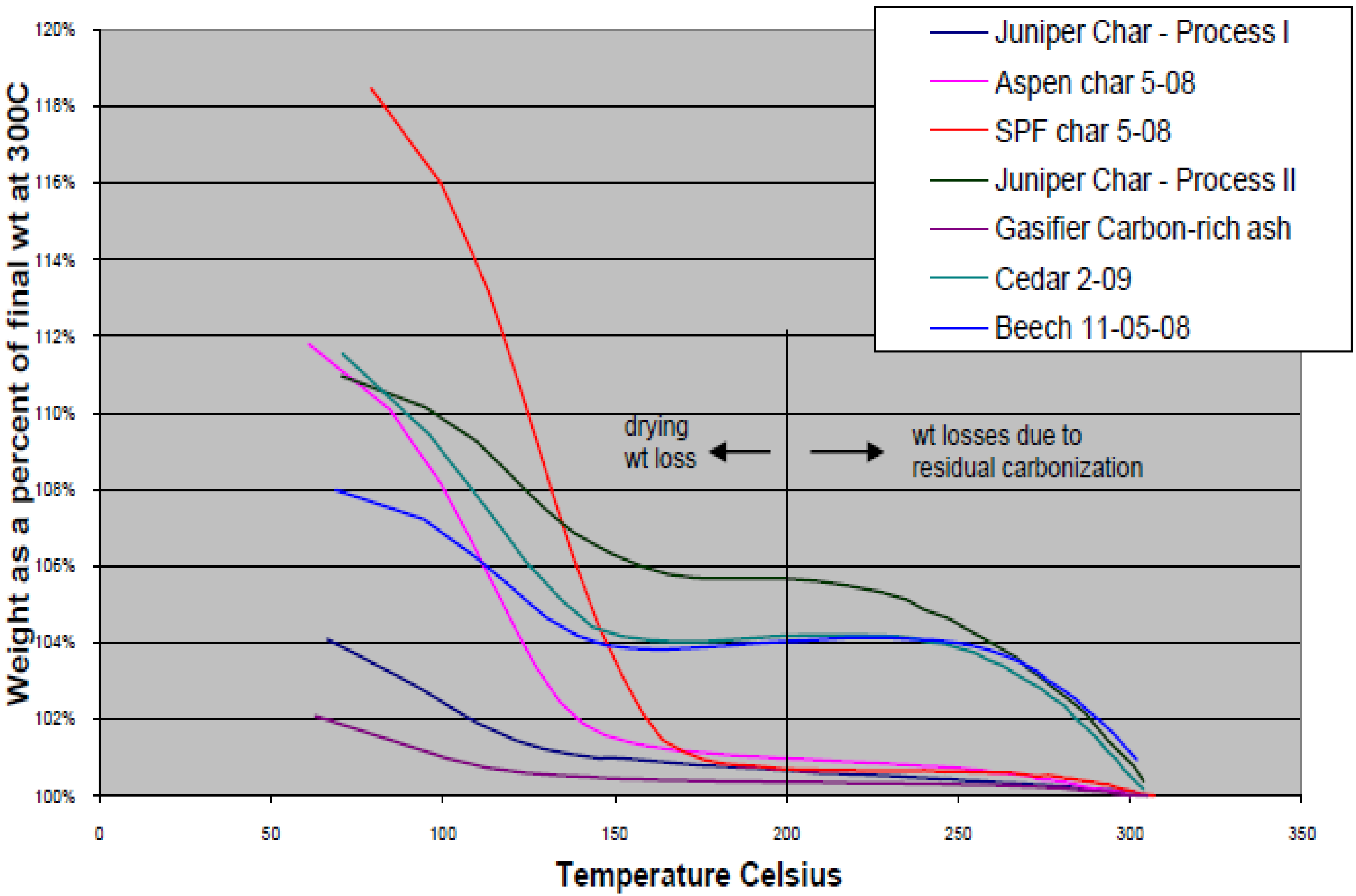
How hard can it be to dry out a porous solid?

If the solid is microporous, and made up of carbonaceous (graphitic) structures, there are several types of moisture:

- Free draining liquid moisture;
- Pore moisture, held by capillary forces;
- Adsorbed moisture, held by short range polarizations (induced dipoles); and even
- Bound water, held by ionic charges at ash defects.

These last two act on exclusively within graphitic micropores, with the characteristic size of 2 nm = 20 Angstroms.

FIGURE 17: WEIGHT LOSS CURVES FOR A SET OF SEVEN CHARS



So, drive off the moisture and move on:

- Unless you also drive off Mobile Matter, which biases the Resident Matter fraction and distorts the Ash measurement by removing non-ash mass.

- Which raises the question: What exactly is being measured when one “assays” the Mobile Matter (aka. Labile Carbon, Volatile Matter, etc.)

Mobile Matter content relates to

- The amount of soluble sugars and readily bio-degradable organics that leach into the soil water and promote soil microbial activity over the period of release (**mostly the first season**).
- The amount of total carbon that should not be allowed if calculating "direct carbon sequestration" (**mostly over the first centuries**) to get rich via "carbon credits" (a la IBI).
- That organic portion of the biochar that is not predominately graphitic, may have a role in evolving Cation Exchange Capacity, and is not resistant to microbial degradation in the soil (**whenever that happens**).

QUESTION: How can ANY analytical method(s) measure and predict properties that span different durations, environments and degradation mechanisms?

ANSWER: It can't and it doesn't. All Mobile Matter assays are flawed, and the ones based on materials other than Biochars are hopelessly flawed (a la IBI, who can't seem to appreciate that biochar is not charcoal, carbon black, coal, et cetera).

NextChar Characterization Matrix

- **Moisture**: weight loss measured upon drying at 150 to 200 Celsius to stable weight in a covered but vented container
- **Dry Bulk Density**: the dried sample is ground as necessary and screened through coarse screen …The screened powder is used to fill a small container to a known volume, and compared to the weight of that volume of water
- **Dry Total Ash**: a sample of the dried and screened material is placed in an open crucible and ashed in air at 550 Celsius until no black residues remain.
- **Dry Mobile Matter**: *1.5 times* the weight loss for a dried sample when heated to 450 Celsius in a vented closed top vial

- **Dry Resident Matter** = 1 – wt% ash – wt% Mobile Matter
- **Dry Ash-free (DAF) Mobile and Resident Matter** weight percentages
- **Calculate weight and volume fractions of everything** (no swelling)

Principal Constituents of Biochar:

- Moisture (as delivered)
- Ash Content (as delivered and from what)
- Mobile Matter versus Resident Matter

- **Cation Exchange Capacity**
  - **ion exchange resin-like behavior**

- **Adsorption Capacity**
  - **activated carbon (adsorption) behavior**

Cation Exchange Capacity or CEC measures the ability of a soil material to exchange cations such as potassium (K+), calcium (Ca++), ammonium (NH4+) and all the major plant micronutrients. CEC is generally attributed to the presence of carboxylic acid functionalities (R-COOH), especially the presence of the deprotonated or anionic form, R-COO-, at intermediate soil pH levels. ……

The challenge with measuring CEC in a biochar is the metric is not stable – it changes over time, it changes when the biochar is subjected to oxidizing conditions, and it changes when the biochar accumulates adsorbed humic and fulvic acids. As a general trend, the CEC of a given biochar will increase from the time the biochar is created, but the future extent and rate of increase are difficult to predict in advance. Increasing biochar CEC is attributed to two phenomena; the oxidation of graphitic plate edges to form additional carboxylic acid functionalities and the adsorption of humic and fulvic acids from soil water. CEC in fresh biochar may also be due to exchangeable protons on mobile matter deposited within the internal surfaces of the biochar, with this CEC likely being lost when the mobile matter solubilizes and departs the associated resident matter.

Furthermore, CEC cannot be "controlled" during pyrolysis (it can be influenced), so don't bother measuring it ……
- unless someone is paying for CEC in the Valuation.

Adsorption is the physical phenomenon where biochar emulates the distinguishing property of activated carbon, which is a non-ionic property whereby soluble organics and chemicals in the soil water are preferentially attracted to the internal surfaces of the biochar. The energy of adsorption is highly dependent on the specific chemical being adsorbed and the local characteristics of the solid surface where the adsorption occurs. Overall, adsorption is a highly dynamic and complicated process, but a very important and unique one in predicting the impact of biochar in soils.

The property of adsorption is usually quantified by measuring how much of a particular adsorbate is taken up by the adsorbent under controlled conditions.

Every method of measuring adsorption has advantages and disadvantages, and this discussion is unlikely to resolve them, nor is that necessary. In general, for the individual researcher, the metric they have used the most tends to be the best metric for guiding their future research efforts.

Overall, adsorption is a property that differing biochars have to greater or lesser extents, and the higher value of one material can be compensated for by the providing more of a lower quality material. The biggest issue is whether there is sufficient total adsorption capacity, the product of the quality times the quantity of the biochar per unit of soil, to accomplish the adsorption-based benefits one is seeking.

The final consideration is the issue of toxicity, and specifically the currently advocated dioxin and PAH assays included in the IBI and EU Biochar Certifications. While it is true that these requirements have found their way into those certifications, it is recommended that such testing be conducted only if the certification is required and therefore, justifies the cost of the testing. The goal of toxicity testing is verify the absence of an unacceptable contaminant in the biochar. **Ironically, any quality biochar strongly binds all currently regulated toxins, so the biochar is the one place that the presence of the toxins is less of a concern.** In addition, the analytical methods used to test for toxic chemicals use **laboratory extraction methods to extract the bound toxins from the biochar, and generate elevated measures relative to the actual bio-availability** of biochar-bound toxins when present in the soil. As such, the issue of toxicity and toxicity testing is not included in this initial phase of biochar testing.

Summary of Measured Properties

- **Moisture** – get rid of it, but you will pay to ship it
- **Dry Bulk Density** – controlled to eliminate particle size biases and allow weights ←→volumes
- **Dry Total Ash**: plant-nutrients, non-carbon mass
- **Dry Mobile Matter**: good predictor of early effects
- Cation Exchange Capacity – not stable, don't bother
- **Adsorption** – unique and differentiating property
- Toxicity – not there unless something is very wrong

August 2016	% moisture	S.G = rho	corrected Wt % MM	Wt % Ash	Wt % RM	ads R134a	DAF R134a
AC1230C std	23.3%	0.549	8.7%	0.7%	90.6%	20.3%	20.4%
Charbon du Bois	5.3%	0.430	14.9%	7.1%	78.0%	3.9%	4.2%
1G Toucan FD=3V	13.6%	0.460	6.5%	3.3%	90.2%	4.7%	4.8%
1G Toucan FD=9V	10.2%	0.379	8.1%	4.6%	87.3%	9.9%	10.4%
DBTK DIY char	49.2%	0.202	22.7%	1.1%	76.2%	8.9%	8.9%
Walnut DIY Char	0.1%	0.568	17.6%	20.9%	61.5%	2.2%	2.8%
Corr Walnut Char	0.1%	0.568	17.6%	3.0%	79.4%	2.2%	2.3%
NextChar II	1.5%	0.184	22.3%	8.1%	69.7%	10.9%	11.8%
NextChar BlaK	15.8%	0.289	14.3%	40.8%	44.9%	7.7%	13.0%
Low C Wood Ash	32.3%	0.778	15.2%	83.9%	0.8%	1.5%	9.1%
Brand A	9.2%	0.191	15.9%	5.2%	78.9%	14.0%	14.7%
Brand B	29.7%	0.224	20.0%	4.9%	75.0%	14.7%	15.5%
Brand C	6.9%	0.224	20.4%	4.1%	75.4%	4.3%	4.5%
Brand D	58.9%	0.266	20.8%	9.4%	69.8%	10.8%	12.0%
Brand E	30.7%	0.375	9.5%	8.0%	82.5%	7.6%	8.2%
Brand F	44.4%	0.410	13.2%	6.2%	80.6%	9.5%	10.1%
Brand G	22.5%	0.743	26.4%	6.5%	67.0%	3.0%	3.2%

description	Brand A	Brand B	Brand C (legacy)	Brand D	Brand E	Brand F	Brand G
INPUT DATA							
wet wt% moisture	9.2	29.7	6.9	58.9	30.7	44.4	22.5
dry wt % total ash	5.2	5.0	4.1	9.4	8.0	6.2	6.5
dry wt % mobile matter	15.9	20.0	20.4	20.8	9.5	13.2	26.4
Biochar dry bulk density (kg/m3)	191.0	224.0	224.0	266.0	375.0	410.0	743.0
Adsorption (wt % of R134a at 100C)	14.0	14.7	4.3	10.8	7.6	9.5	3.0
Water - kg per cubic meter	19.3	94.6	16.7	381.5	165.7	327.0	215.2
Bulk Bag weight - kg/m3	210.3	318.6	240.7	647.5	540.7	737.0	958.2
Water - pounds/yd3	32.5	159.5	28.1	643.1	279.4	551.2	362.8
Bulk Bag weight - pounds/yd3	354.4	537.1	405.6	1091.4	911.4	1242.3	1615.1
dry wt% resident matter	78.9	75.1	75.5	69.8	82.5	80.6	67.1
Ash - kg per cubic meter	9.9	11.1	9.2	25.1	29.9	25.3	48.5
Mobile Matter - kg/m3	30.4	44.8	45.7	55.3	35.6	54.1	196.2
Resident Matter - kg/m3	150.8	168.1	169.1	185.6	309.5	330.6	498.3
Ads - kgs R134a per dry metric ton	140	147	43	108	76	95	30
Ash - volume %	0.4	0.4	0.4	1.0	1.2	1.0	1.9
Mobile Matter - volume %	3.0	4.5	4.6	5.5	3.6	5.4	19.6
Resident Matter - volume %	10.1	11.2	11.3	12.4	20.6	22.0	33.2
Dry Voidage - volume %	86.5	83.9	83.8	81.1	74.6	71.5	45.2
Ads - kgs R134a per cubic meter	26.7	32.9	9.6	28.7	28.5	39.0	22.3

description	Brand A	Brand D	Brand G
INPUT DATA			
wet wt% moisture	9.2	58.9	22.5
dry wt % total ash	5.2	9.4	6.5
dry wt % mobile matter	15.9	20.8	26.4
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Water - kg per cubic meter	19.3	381.5	215.2
Bulk Bag weight - kg/m3	210.3	647.5	958.2
Water - pounds/yd3	32.5	643.1	362.8
Bulk Bag weight - pounds/yd3	354.4	1091.4	1615.1

description	Brand A	Brand D	Brand G
dry wt% resident matter	78.9	69.8	67.1
Ash - kg per cubic meter	9.9	25.1	48.5
Mobile Matter - kg/m3	30.4	55.3	196.2
Resident Matter - kg/m3	150.8	185.6	498.3
Ads - kgs R134a per dry metric ton	140	108	30
Ash - volume %	0.4	1.0	1.9
Mobile Matter - volume %	3.0	5.5	19.6
Resident Matter - volume %	10.1	12.4	33.2
Dry Voidage - volume %	86.5	81.1	45.2
Ads - kgs R134a per cubic meter	26.7	28.7	22.3

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Measuring biochar properties to establish Valuation

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August, 2016

NextChar Characterization Matrix - Measuring biochar properties to establish Valuation

By Hugh McLaughlin, PhD, PE – CTO – NextChar.com August 10, 2016 draft

Biochar is maturing as both a concept and market. In order to continue to grow, the historic mandate for a biochar characterization system needs to be filled ASAP. While IBI has promoted their leadership in this area since 2009, and orchestrated an exhaustive process that has resulted in the current IBI Certification Program and the associated IBI Biochar Standards, the current offerings are not proving popular nor effective in the marketplace. De facto, the current IBI approach seems devoid of measures establishing positive "value" of a given biochar and more focused on "proving the absence of contaminants" and lumping biochars into broad classes that mask relevant differences between commercially available products.

The goal of this paper is to propose a set of simple, affordable and routinely accessible tests that will provide a set of metrics that characterize a given biochar and will serve as the starting point for comparison and valuation of biochars. For many high quality biochars, this set of metrics may be all that is needed to satisfy the purchasing public. For biochars that have one or more low metrics, the tests will highlight which aspects of the biochar merit additional consideration prior to utilization as a soil amendment or remediation treatment. The reporting of the test metrics will serve as a requirement for the laying claim that a material is "biochar"; lower quality biochars will be reflected in correspondingly lower metrics, but there will not be any required thresholds.

The suite of tests and the associated biochar metrics are intended for testing raw unmodified biochar. It is clear that many post-pyrolysis steps can be performed that modify the original "biochar" and influence the subsequent performance in the soil. To the extent those modifications are part of creating the initial biochar, such as quenching into water, and to the extent those modifications persist throughout the life of the biochar in the soil, then the biochar should be tested post-modification. To the extent the modifications provide initial or first season crop benefits, only to fade away before subsequent growing seasons, such modifications should not be present during the biochar testing, if possible. If not possible, then the testing should proceed on the modified biochar with appropriate notation on the reported metrics.

The tests are intended to broadly characterize a biochar by the scheme developed in Chapters 7 and 8 of "The Biochar Revolution", where biochar is conceptually broken into mobile and resident matter, with mobile matter dissolving over time and resident matter remaining as dispersed solids in the soil. Each group can be further partitioned into organic and inorganic fractions, and the fractions further characterized depending on additional metrics, such as chemical and physical properties.

The baseline characterization of any biochar consists of a small number of low-cost tests that will partition the biochar into water, ash, mobile matter and resident matter. Mobile matter is that portion of biochar that leaves the biochar over the initial few growing seasons, and corresponds to portions called volatile matter or labile matter by others. Since it is measured with a specified method, it is given a unique name. By the same logic, resident matter denotes the fixed carbon or recalcitrant matter within the biochar, and uniquely named to tie the results to the method of measurement.

The following initial series of measurements is proposed, with a brief description of the analytical steps, followed by a discussion of the measurements derived from them.

1) **Moisture**: weight loss measured upon drying at 150 to 200 Celsius to stable weight in a covered but vented container; duration of heating is dependent on the level of moisture in the initial sample. This test can be performed in any laboratory oven, or even a toaster oven, with appropriate temperature control. The higher drying temperature assures that adsorbed moisture is removed from the micropores of the biochar (see Chapter 8, page 94, of *The Biochar Revolution* book for the discussion and supporting data).

2) **Dry Bulk Density**: the dried sample is ground as necessary and screened through coarse screen, such as found on a screened window to keep insects outdoors. Larger particles can be omitted unless they represent a specific fraction of a heterogeneous biochar. The screened powder is used to fill a small container to a known volume or depth, typically full, and subject to gentle tapping at the container side to settle, but not crush, the particles. The container is weighed then emptied, filled to the same volume with clean water and weighed again. The ratio of the weight of the biochar to the weight of the water is the biochar specific gravity, which can be converted appropriate units for various size packaging. This method does not accurately predict the density of uncrushed biochar in large bulk containers due to the presence of an unknown level of moisture and the larger range of particle sizes, but provides several metrics related to the composition of the biochar, as will be further discussed.

3) **Total Ash**: a sample of the dried and screened material is placed in an open crucible and ashed in air at 550 Celsius until no black residues remain. The weight remaining after "ashing" of the dried sample is treated as the total ash present in the sample. Chapter 8, page 97, of *The Biochar Revolution* book provides a simple method that does not require a laboratory muffle furnace, but also does not provide accurate temperature control. As such, it is a lower cost, less accurate method that is useful for less rigorous applications, but is not recommended for biochars being commercially transacted.

4) **Mobile Matter**: the weight loss for a dried sample when heated to 450 Celsius in a vented closed top vial provides a measure that can be used to predict the relative partition of mobile and resident matter in a biochar sample. A sample of the dried and screened material is placed in a

glass vial with a single pinhole in the center of the cap (search ebay for “glass sample vials with aluminum cap 8 ml – they cost about $1 each via China). The cap liner is removed and the vial is dried as on step 1 above. This test requires a fairly accurate temperature controller, since the 450 Celsius is critical for the accurate partitioning of the mobile matter from the resident matter. The accuracy of the assay and methods for improving the prediction of resident matter are discussed in the data reduction section below.

Based on the four measurements above, the following metrics can be calculated for a specific biochar sample. The calculation method is discussed briefly and clarified if it is non-obvious.

1) Weight percent moisture on a wet or as-received basis (self-explanatory)
2) Weight percent ash on a dry basis (self-explanatory)
3) Contribution of ash to dry bulk density = dry bulk density * wt % ash
4) Contribution of organic matter to dry bulk density = dry bulk density * (1 - wt % ash)
5) Dry weight percent Mobile Matter = percent wt loss upon heating to 450C * 1.5 (the 1.5 factor accounts for the additional mobile matter that converted to resident matter during the heating to 450 C, as discussed below).
6) Dry weight percent Resident Matter = 1 – wt% ash – wt% Mobile Matter
7) Ash-free (normalized) Mobile and Resident matter weight percentages (self-explanatory)

The use of a factor of 1.5 in item 5 above requires clarification. The assay for mobile matter heats the dried biochar to 450C, during which time any volatiles may either vaporize or carbonize into additional resident matter and a lesser amount of volatiles. As such, when partially carbonized biomass is heated, the observed weight loss does not represent a direct measure of the total volatiles present in the starting biomass. For example, pure uncarbonized wood typically losses 70 to 75 wt% of its mass as volatiles during total conversion to a 900 C char, leaving 25 to 30 wt% as char – yet the starting biomass would degrade entirely as mobile matter if introduced into the soil as uncarbonized wood.

The factor of 1.5 is intended to correct for this phenomenon, while acknowledging that the exact factor is specific to any unique biochar production process. The factor of 1.5 is intended to err on the conservative side, by overestimating mobile matter content in cases where heating result in significant weight loss. As the weight loss during heating to 450C decreases, the magnitude of the mobile matter correction similarly decreases.

The data available in the study titled “Schenkel and Shenxue revisited”, presented at the Biochar2010 Conference, Ames, Iowa and downloadable from acfox.com/biochar references, was used to develop the 1.5 factor. Applying this factor to the measured mobile matter levels from that study generated the trends shown in Figure 1. The trends shown for the Resident Carbon represent the calculated carbon content of the Resident Matter (potentially for the purposes of calculating carbon sequestration credits), using the same 1.5 factor. As can be seen, both corrections diminish as the level of mobile matter decreases at higher carbonization temperatures.

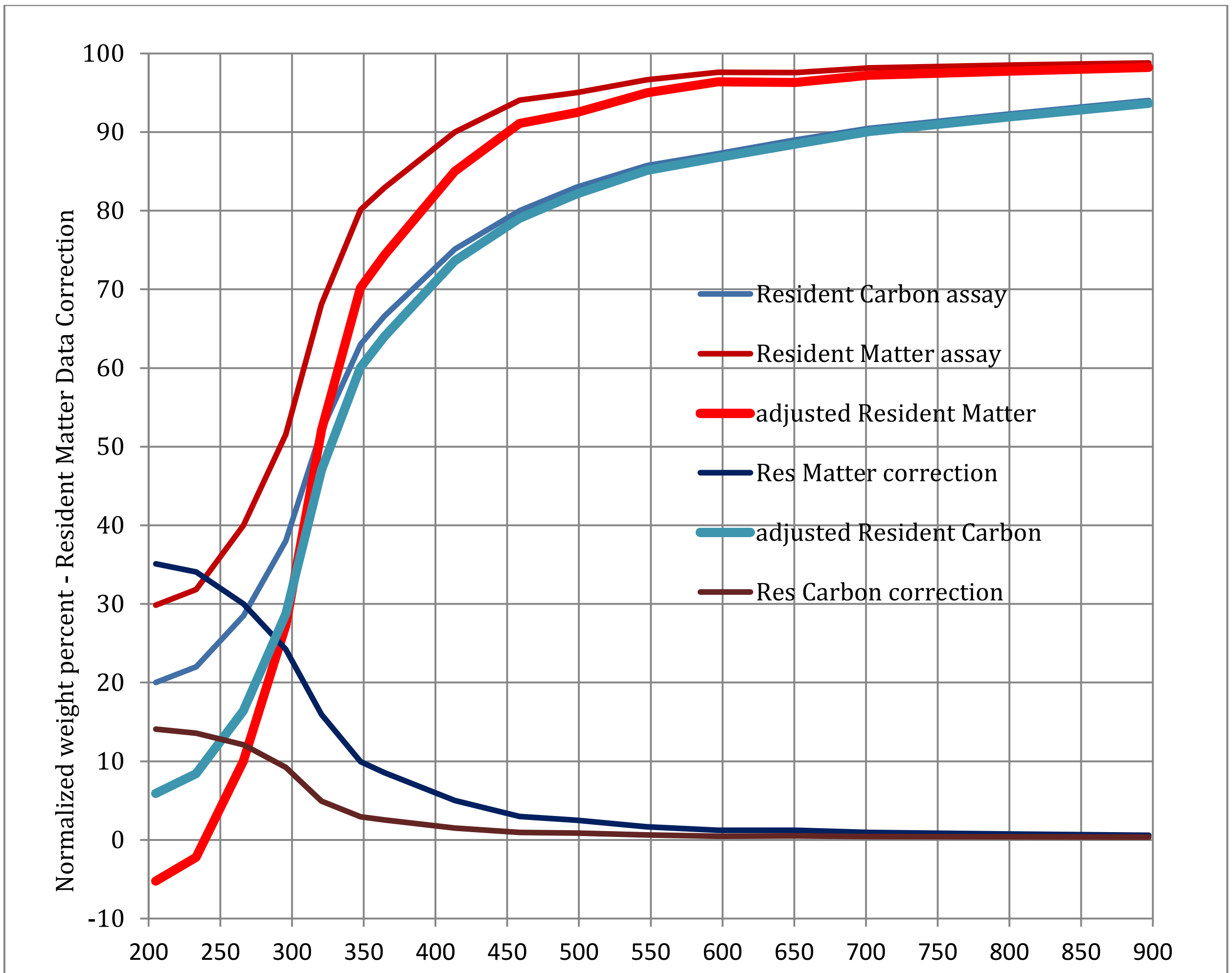

Figure 1: Temperature of Carbonization in Celsius

As can be seen in the trends in Figure 1, any biochar that has been produced at temperatures below 240C has no adjusted Resident Matter and negligible adjusted Resident Carbon. All biochars produced below 400C have significant corrections associated with the high level of volatiles and the associated correction being applied to generate the adjusted Resident Matter and Carbon metrics. Above 400C, and for any biochar evidencing low levels of volatilization weight loss upon heating to 450C, the adjustment is minor and decreasing as the level of volatiles decreases.

Based on the above simple assays, the biochar is well characterized with respect to physical properties and a basis is created to partitioning a volume or weight of biochar into the various constituents that correspond to distinct soil properties and growing phenomena. For example, the total ash is potentially a valuable source of liming and plant nutrients, including potassium and phosphorus, and biochars claiming value for those constituents should further report that specific levels of inorganic plant nutrients. The mobile matter is generally less desirable than the resident matter over the longer time frame, but may be desirable for utilization in sterile soils where microbiology is deficient. The optimal partitioning of biochar constituents will depend on the ultimate utilization of the biochar, with the characterization assisting in matching the biochar properties to the intended soil impacts.

Absent from the baseline characterization are the chemical characterizations of the biochar, which measure properties such as Cation Exchange Capacity and adsorption, in addition to addressing concerns about potential toxicity of the biochar, due to the presence of specific chemicals entering the biochar via the feedstock or created during conversion to biochar. Due to the nuances of each of these aspects of an individual biochar, they will be discussed separately.

Cation Exchange Capacity or CEC measures the ability of a soil material to exchange cations such as potassium (K+), calcium (Ca++), ammonium (NH4+) and all the major plant micronutrients. CEC is generally attributed to the presence of carboxylic acid functionalities (R-COOH), especially the presence of the deprotonated or anionic form, R-COO-, at intermediate soil pH levels. While the specific interactions of soil CEC are highly dependent on the local chemistry and microbiology in the soil, the merits of having sufficient CEC present is well established. Fortunately, many soil components possess CEC to varying degrees; clays represent large potential capacities that are usually only partially available at any time and certain types of soil organic matter, such as humates, represent a large portion of the active soil CEC.

The challenge with measuring CEC in a biochar is the metric is not stable – it changes over time, it changes when the biochar is subjected to oxidizing conditions, and it changes when the biochar accumulates adsorbed humic and fulvic acids. As a general trend, the CEC of a given biochar will increase from the time the biochar is created, but the future extent and rate of increase are difficult to predict in advance. Increasing biochar CEC is attributed to two phenomena; the oxidation of graphitic plate edges to form additional carboxylic acid functionalities and the adsorption of humic and fulvic acids from soil water. CEC in fresh biochar may also be due to exchangeable protons on mobile matter deposited within the internal surfaces of the biochar, with this CEC likely being lost when the mobile matter solubilizes and departs the associated resident matter.

Because the CEC of the native biochar does not accurately reflect the dynamic CEC contribution the biochar ultimately makes in the soil, it is recommended that CEC measurements be de-emphasized in the as-produced market valuation of biochars. Furthermore, once the biochar becomes part of a living soil, with active soil biota, the initial biochar CEC is a minor and variable component in the overall ionic balances within the living soil.

Adsorption is the physical phenomenon where biochar emulates the distinguishing property of activated carbon, which is a non-ionic property whereby soluble organics and chemicals in the soil water are preferentially attracted to the internal surfaces of the biochar. The energy of adsorption is highly dependent on the specific chemical being adsorbed and the local characteristics of the solid surface where the adsorption occurs. Overall, adsorption is a highly dynamic and complicated process, but a very important and unique one in predicting the impact of biochar in soils.

The property of adsorption is usually quantified by measuring how much of a particular adsorbate is taken up by the adsorbent under controlled conditions. There are many different combinations of adsorbates and conditions and they all correspond to different situations where the extent of adsorption makes a difference in the local environment. The quantity is usually described as an amount of uptake per unit of weight or volume of adsorbent under the controlled conditions.

One test method is the weight increase due to the uptake of pure R134a, a fluorocarbon refrigerant, as the adsorbate or challenge gas, on dry biochar at 100C at a pressure of one atmosphere, known as the GACS Adsorption Capacity. Another assay is the weight increase due to the uptake of n-butane on dry biochar at 25C at a pressure of one atmosphere, called the Biochar Butane Activity after the ASTM D-5742 Standard Test Method for Determination of Butane Activity of Activated Carbon. Additional tests for adsorption include BET surface area assays using Nitrogen and Carbon Dioxide as the challenge gases under controlled conditions of pressure and temperature.

Every method of measuring adsorption has advantages and disadvantages, and this discussion is unlikely to resolve them, nor is that necessary. In general, for the individual researcher, the metric they have used the most tends to be the best metric for guiding their future research efforts.

Overall, adsorption is a property that differing biochars have to greater or lesser extents, and the higher value of one material can be compensated for by the providing more of a lower quality material. The biggest issue is whether there is sufficient total adsorption capacity, the product of the quality times the quantity of the biochar per unit of soil, to accomplish the adsorption-based benefits one is seeking. Furthermore, the adsorption property of a biochar is understood to be created during the pyrolysis process that converts the biomass to biochar, and does not increase over time, in contrast to the CEC property of biochar. As such, it is a critical property to measure on a clean raw biochar, in order to accurately gauge whether adsorption phenomena will play a role in the long-term impact the biochar will bring to the soil.

Since there are several options for quantifying adsorption, it is recommended that a method be adopted that allows comparison of different biochars evaluated by different methods. In order to do this, there needs to be a reasonable standard to be used as a reference material, with the performance of any biochar being measured as the percentage of the performance of the standard under the same conditions. Fortunately, the activated carbon industry provides a large selection of readily available materials that can serve as standards.

In order to allow for flexibility, the actual adsorption metric can be reported as “XX percent of the adsorption of reference material YY, as measured by: insert name of analytical test or brief description of adsorption condition. An example might be “Biochar ABC measured 45% of the adsorption performance by weight of F-400 activated carbon as measured by the ASTM D-5742 Butane Activity Test”. Another acceptable reporting would be “Biochar DEF measured 80% of the adsorption of very high quality coconut shell activated carbon as measured by the removal of tannins from river water at room temperature”. It is clear that the second reporting provides a claim of higher adsorbency via a less credible method – this tradeoff is up to both the manufacturer of the biochar and the consumer of the material to consider. At the current level of maturity of the biochar marketplace, it is more important to report what is known than to omit available information due to a lack of consensus.

Because the science of adsorption is so problematic when applied to materials as variable as biochars, it is requested that every party reporting an adsorption metric supply sufficient information to allow others to duplicate the analytical procedure. This will have the advantage of educating others as to alternative methods of measuring adsorption, and allow individuals to confirm the claims of the label relative to the performance of the actual material. In the absence of the ability to replicate an analytical method that claims to measure the adsorption metric of a given biochar, it is recommended that the adsorption claim reported be disregarded.

There are two situations where measuring and reporting adsorption is more problematic; each will be briefly discussed. The first is where the biochar is blended with other soil amendments or additives that will occupy existing adsorption capacity in the biochar and make it difficult to measure the presence of such modifications. In this case, it is recommended that the label describe the original biochar material that was utilized on the blended product and include any options for identifying the unadulterated material, such as “Includes 30 % by volume – insert Brand Name of pure material – biochar, blended with organic molasses to accelerate soil microbe growth”, where the named product is also available as the pure material if additional testing is desired by the consumer.

Any biochar with elevated levels of mobile matter is the second situation that complicates the measurement of adsorption. Generally, elevated mobile matter is indicative of lower overall biochar quality. Unfortunately, elevated mobile matter can cause both elevated and depressed levels of measured adsorption, without any accurate means to determine which may be occurring. Mobile matter can block adsorption sites, lowering the measured adsorbancy, but it can also *absorb* the challenge gas (like a baby's diaper swelling up as it accumulates liquids) and impersonate elevated uptake of the challenge gas. The problem is the ***ab****sorption* phenomenon is restricted to the very concentrated challenge gas levels used during the adsorption assay, and are not reflective of conditions likely to be encountered in the soil. Thus, the mobile matter is doing something that will not happen in the soil and will disappear once the mobile matter leaves the biochar, so the measured "absorbency" represents a false-positive indication of adsorption capacity due to the presence of the excess mobile matter in the biochar. Fortunately, as a counter-balancing trend, those applications that benefit from high mobile matter biochars are generally less focused on the specific benefits that **ad**sorbency causes in the soil, such as detoxification and tolerance to desiccating growing conditions.

The final consideration is the issue of toxicity, and specifically the currently advocated dioxin and PAH assays included in the IBI and EU Biochar Certifications. While it is true that these requirements have found their way into those certifications, it is recommended that such testing be conducted only if the certification is required and therefore, justifies the cost of the testing. The goal of toxicity testing is verify the absence of an unacceptable contaminant in the biochar. Ironically, any quality biochar strongly binds all currently regulated toxins, so the biochar is the one place that the presence of the toxins is less of a concern. In addition, the analytical methods used to test for toxic chemicals use laboratory extraction methods to extract the bound toxins from the biochar, and generate elevated measures relative to the actual bio-availability of biochar-bound toxins when present in the soil. As such, the issue of toxicity and toxicity testing is not included in this initial phase of biochar testing.

In summary, this core set of biochar metrics generates a standardized characterization of biochars that are openly marketed and generates comparative metrics that can be used to calculate valuation based on the properties of the biochar, as produced. The ability of these properties to predict subsequent performance and value in actual biochar applications will be vetted by the experiences and feedback from the marketplace. As is often the case, "the proof of the pudding is in the eating" (Cervantes).