Biochar

Crops

	Identification of Petitioned Substance	

3

4	**Chemical Name:**	12 **Trade Names:**
5	Carbon	13 N/A
6		14
7	**Other Names:**	**CAS Numbers:**
8	Charcoal	Carbon: 7440-44-0
9	Biochar	
10	Agrichar	**Other Codes:**
11		EINECS No. 231-153-3

15

	Summary of Petitioned Use	

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18 The United States Department of Agriculture (USDA) National Organic Program (NOP) has defined
19 biochar as "a biomass that has been carbonized or charred" and classified it as a non-synthetic substance
20 via guidance from NOP 5034-1 (NOP 2016a). Additionally, NOP stipulates that "[biochar] sources must be
21 untreated plant or animal material," and the "pyrolysis process must not use prohibited additives" (NOP
22 2016a). However, the USDA organic regulations prohibit the use of non-synthetic "ash from manure
23 burning" at 7 CFR 205.602.

24

25 A petition submitted to the National Organic Standards Board (NOSB) by Mark Stoermann on December 6,
26 2019 seeks to amend the restrictions on biochar produced from a cow manure source that has been applied
27 to the substance according to the restrictions on "ash from manure," described at 7 CFR 205.602 (USDA
28 2019). This petition states that biochar produced from cow manure has been misclassified as ash from
29 manure burning. The petition describes the improved agricultural and environmental outcomes that have
30 been associated with the application of biochar from cow manure when compared to the manure itself.

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32 This report addresses biochar generally, as requested by the NOSB, including biochar made from plant or
33 animal sources such as manure from cows and other animals. This report compares biochar to both
34 activated charcoal and ash to clarify its classification as a substance that is distinct from both. This report
35 details the most common biochar production methods and its agricultural and environmental applications.

36

	Characterization of Petitioned Substance	

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39 Biochar has many applications within agriculture and beyond. It is a common modern soil amendment
40 with historic roots that has been reported to improve soil quality, crop yields, microbial populations, soil
41 pH, and water retention (Sohi et al. 2009, Verheijen et al. 2010, Cox et al. 2012, Lehmann and Joseph 2015,
42 Tenic et al. 2020). Biochar is also being explored as a method to mitigate the effects of climate change and
43 greenhouse gases through carbon sequestration (Clough and Condron 2012, Lehmann and Joseph 2015,
44 Hagemann et al. 2018). Further, biochar has purification applications and next generation materials that
45 may serve multiple purposes, including purification followed by carbon sequestration (Renner 2007, Cao
46 and Harris 2010, Park et al. 2011, Ippolito et al. 2012, Agrafioti et al. 2013, Qian et al. 2015, Tenic et al. 2020).

47

48 *Activated charcoal vs. biochar*

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50 Activated charcoal, a substance with many similarities to biochar, is approved as a "synthetic substance
51 allowed for use in organic livestock production," with the stipulation that it is produced "from vegetative
52 sources" at 7 CFR 205.603. Activated charcoal from vegetative sources is also classified as a synthetic

53   substance in the USDA organic regulations at § 205.605(b) and is allowed for use as a filtering aid for
54   processed products labeled "organic" or "made with organic."

56   Both activated charcoal (also referred to as activated carbon) and biochar are classified as pyrogenic
57   carbonaceous materials (PCMs). PCMs are produced by the thermochemical conversion of a feedstock
58   source of biomass (e.g., wood chips, grasses, crop remnants, manures) that contains organic carbon
59   originating from a biological source in a limited-oxygen environment (Renner 2007, Cox et al. 2012,
60   Anderson et al. 2013, Verheijen et al. 2010, Hagemann et al. 2018, Wang J et al. 2019, Tenic et al. 2020).
61   These two substances are similar in elemental composition and chemical structure, but they serve different
62   functions (Hagemann et al. 2018). Activated charcoal is primarily used for its high sorbent value, most
63   often for purification, while biochar is primarily used for soil applications and carbon sequestration;
64   however, more recently the two substances have been used increasingly interchangeably (Schanz and
65   Parry 1962, Glaser et al. 2002, Spokas et al. 2012, Anderson et al. 2013, Werner et al. 2017, Hagemann et al.
66   2018).

68   Activated charcoal and biochar differ in how they are produced. Biochar is produced by the thermal
69   decomposition of biomass in a limited-oxygen environment to prevent oxidation of the organic carbon
70   material (Renner 2007, Cox et al. 2012, Anderson et al. 2013, Verheijen et al. 2010, Lehmann and Joseph
71   2015, Hagemann et al. 2018). Biochar is the resulting solid product of the thermal decomposition process
72   (Verheijen et al. 2010, Cox et al. 2012, Hagemann et al. 2018, Tenic et al. 2020). Limited-oxygen thermal
73   decomposition may also be used in the production of activated charcoal, making biochar a potential
74   precursor for activated charcoal production; however, this substance requires an additional activation step,
75   which increases its sorption abilities by dramatically increasing the surface area of the carbon substrate
76   (USDA 2002, Hagemann et al. 2018). The charcoal may be activated via chemical or physical means (USDA
77   2002, Hagemann et al. 2018). Chemical activation requires an activation agent such as zinc(I) chloride
78   (ZnCl), iron(III) chloride ($FeCl_3$), sulfuric acid (H_2SO_4), phosphoric acid (H_3PO_4), hydrochloric acid (HCl),
79   nitric acid (HNO_3), sodium or potassium hydroxide (NaOH/KOH), or sodium or potassium carbonate
80   ($NaCO_3/KCO_3$) (USDA 2002, Marsh and Reinoso 2006, Hagemann et al. 2018). Physical activation of the
81   charcoal uses gases to increase the surface area, including air, steam (H_2O), nitrogen (N_2), and carbon
82   dioxide (CO_2) (USDA 2002, Marsh and Reinoso 2006, Hagemann et al. 2018). Alternatively, activated
83   charcoal can also be produced in a way that combines thermal decomposition and activation into a single
84   step (Marsh and Reinoso 2006, Hagemann et al. 2018).

86   *Ash vs. biochar*

88   The general term "ash" is defined as "a residue which is a powder, left after a material has been burned
89   completely, e.g., the ash after wood or plants have been burned" (Godman 1982). While this definition
90   refers to complete combustion of a substance, it has also been applied to incomplete combustion (NOP
91   2016a, NOP 2016b). In this general context, biochar, a solid produced through thermal decomposition of
92   biomaterial, could be classified as ash. However, portions of the literature differentiate biochar from ash,
93   describing them as separate products from thermal decomposition processes (e.g., combustion, pyrolysis,
94   torrefaction, gasification) (Cox et al. 2012). The key distinction between biochar and ash appears to be
95   related to the amount of oxygen present and the temperature of the decomposition process, with high
96   oxygen concentrations and/or temperatures producing ash and low oxygen concentrations and/or
97   temperatures producing biochar (Cox et al. 2012).

99   Within the literature, ash is listed as a component of biochar rather than the entirety of the substance.
100   Specifically, the literature describes the ash component of biochar in relation to the mineral content of the
101   substance, as shown in Table 1 in the Composition of the Substance section below (Demibras 2004,
102   Verheijen et al. 2010, Spokas et al. 2012). The ash, or mineral, part of biochar is composed of various salts
103   and nutrients; the amount of ash and its composition vary based on the biochar feedstock (Verheijen et al.
104   2010, Spokas et al. 2012, Qian et al. 2015, Tenic et al. 2020). In the context of this report, the term "ash" will
105   be used to refer to the mineral content of biochar, not the general definition of combustion residues. The
106   ash, or mineral, content of biochar is discussed in greater detail in the Composition of the Substance section
107   and is highlighted in Table 2.

108
109 **<u>Composition of the Substance:</u>**
110 Biochar is a substance that is not uniform in production and composition (Verheijen et al. 2010, Cox et al.
111 2012, Lehmann and Joseph 2015, Hagemann et al. 2018, Tenic et al. 2020). There are many possible
112 feedstocks for biochar production, presenting a great deal of chemical diversity (Verheijen et al. 2010, Cox
113 et al. 2012, Tenic et al. 2020). Moreover, there are many different conditions for the production of biochar,
114 which can yield a large range of potential compositions (Verheijen et al. 2010, Cox et al. 2012, Tenic et al.
115 2020). These considerations make a general discussion of biochar composition difficult, as illustrated in
116 Table 1, which details the diversity in average composition across several sources of biochar.
117
118

Table 1: Average range of biochar components

Component	Weight/weight %
Fixed carbon	50–90
Volatile compounds	0–40
Moisture	1–15
Mineral content (ash)	0.5–55

119   Sources: Antal and Gronli 2003, Sohi et al. 2009,
120   Verheijen et al. 2010, Lehmann and Joseph 2015

121
122 Fixed carbon represents the structure of biochar comprised of crystalline graphene (carbon [C]), which tend
123 to stack on top of one another to maximize interactions between pi electrons in the ring structures and
124 amorphous aromatic structures that include the bulk of hydrogen (H) atoms and heteroatoms (e.g.,
125 nitrogen [N], oxygen [O], sulfur [S]) (Sohi et al. 2009, Verheijen et al. 2010, Lehmann and Joseph 2015).
126 Volatile compounds are produced during the thermal degradation of the biomass and are dependent on
127 the biochar feedstock (Spokas et al. 2012). The most common volatile compounds liberated during biomass
128 processing are tars, various hydrocarbons, molecular hydrogen (H_2), carbon monoxide (CO), and carbon
129 dioxide (CO_2) (Baldock and Smernik 2002, Demibras 2004, Verheijen et al. 2010, Wang J et al. 2019).
130 Moisture is in the form of residual water (H_2O), which also varies depending on feedstock and production
131 conditions.
132
133 The mineral content of the biochar, in the form of ash, is responsible for the majority of the substance's
134 nutrient value (Verheijen et al. 2010, Qian et al. 2015). The nutrient composition of biochar is dependent on
135 both feedstock and production conditions, and some trends have been noted. Animal manures and sewage
136 sludge tend to result in biochar that is rich in potassium (K) and phosphorus (P) but has a relatively low
137 carbon content (C) (Tenic et al. 2020). Wood products tend to result in biochar that is rich in organic matter
138 (carbon [C]) but relatively low in nitrogen (N), phosphorus (P), and potassium (K) (Tenic et al. 2020). Crop
139 residues (e.g., leafy matter, stalks, roots, etc.) tend to result in a balance between manure and wood
140 biochar, while some crops provide a boost in a specific nutrient (Tenic et al. 2020). A breakdown of
141 nutrients from a range of feedstocks is presented in terms of elemental composition in Table 2.
142
143 The NOP has requested additional information on compounds that may have been carried over from raw
144 biomass sources (e.g., pesticides in crop residues, residues in manures). The identification of specific
145 compounds in biochar is not discussed in the literature. At the time of this report, the author found no
146 specific discussions of feedstock compounds or residues carried over into biochar. The lack of reports
147 discussing traceable compounds and residues may be due to the complex and heterogeneous nature of
148 biochar, which makes identification of specific compounds difficult. Additionally, it is likely that most
149 organic compounds present in raw feedstock are converted to other compounds during production
150 processes, as has been reported to occur with organic pollutants (Hagemann et al. 2018). Literature reports
151 characterize biochar based on elemental analyses, carbon to nitrogen ratios, and the prevalence of minerals
152 and nutrients (characterized as ash), as illustrated in Table 1 above (Al-Wabel et al. 2018, Kalus et al. 2019,
153 Varjani et al. 2019, Wang et al. 2020). While specific residues are not traced from feedstock to biochar,
154 manure feedstocks are frequently reported as having relatively high concentrations of ash (metal nutrients
155 such as calcium, potassium, sodium, magnesium, and calcium) and nitrogen and phosphorous nutrients
156 (Spokas et al. 2012, Agrafioti et al. 2013, Al-Wabel et al. 2018, Wang et al. 2020).
157

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Table 2: Elemental composition of biochar

Feedstock	Nitrogen (N) %	Phosphorus (P) %	Potassium (K) %	Calcium (Ca) %	Carbon (C) %
Green waste	0.14–1.7	0.01–0.27	0.06–1.49	<0.01–2.05	36 - 78
Sugarcane products	1.2–1.4	0.25–3.4	0.35–2.0		24–68
Wood chips or bark	<0.01–1.04	<0.01–0.27	0.145–0.27	0.171–0.98	40 - 85
Papermill sludge	0.31–0.48	N/A	0.22–1.0	6.2–11	50–52
Macadamia shells	0.49	0.02	0.18	0.099	90
Bamboo	1.2	0.55	0.36	0.41	77
Cow manure	1.2	0.3	1.9	1.0	73
Poultry litter	2–3.5	2.4–3.59	2.8–5.9	4.0–5.04	38–42
Paunch waste	0.69	0.51	0.50	1.5	47
Human biosolids	2.2	5.7	0.19	5.5	21
Average Biochar	**Nitrogen (N) 22.3 g/kg**	**Phosphorus (P) 23.7 g/kg**	**Potassium (K) 24.3 g/kg**	**Calcium (Ca) not measured**	**Carbon (C) 543 g/kg**

159 Sources: Yamato et al. 2006, Chan et al. 2007, Gundale and De Luca 2007, Rondon et al. 2007, Chan et al.
160 2008, Gaskin et al. 2008, Kimetu et al. 2008, Kolb et al. 2009, Singh et al. 2010, Quirk et al. 2010, Van Zweiten
161 et al. 2010a, Van Zweiten et al. 2010b, Van Zweiten et al. 2010c, Verheijen et al. 2010, Cox et al. 2012,
162 Lehmann and Joseph 2015.

163

164 **<u>Source or Origin of the Substance:</u>**
165 Biochar is known in nature primarily as the product of forest fires (Verheijen et al. 2010, Wang J et al. 2019).
166 However, nearly all biochar is produced by the thermochemical degradation of biomass in the absence of
167 oxygen (Verheijen et al. 2010, Cox et al. 2012, Qian et al. 2015, Hagemann et al. 2018, Tenic et al. 2020).
168 Biochar can be produced from a range of feedstocks from both plant and animal sources. These sources
169 include nut shells, sugarcane bagasse, coconut husks, cotton, crop remnants, grain remnants, grass
170 residues, wood chips, tree back, organic waste, animal bedding, livestock manure, poultry litter, sewage
171 sludge, paper sludge, and municipal waste (Sohi et al. 2009, Clough and Condron 2010, Verheijen et al.
172 2010, Park et al. 2011, Cox et al. 2012, Spokas et al. 2012, Agrafioti et al. 2013, Bayabil et al. 2015, Lehmann
173 and Joseph 2015, Tenic et al. 2020).

174

175 The NOP has requested additional information about the biomass feedstocks used in biochar production.
176 The literature on biochar does not provide much information about the biomass sources and how these
177 sources are obtained. The literature discusses these feedstocks in general terms as waste products from
178 various industries (Verheijen et al. 2010, Cox et al. 2012, Anderson et al. 2013, Hertsgaard 2014, Al-Wabel et
179 al. 2018, Hagemann et al. 2018, Ji et al. 2019, Kalus et al. 2019, Oni et al. 2019, Varjani et al. 2019, Wang J et
180 al. 2019, Khalid et al. 2020, Lao and Mbega 2020, Shalini et al. 2020, Tenic et al. 2020). The literature
181 generally references the sustainable nature of biomass used as biochar feedstocks, as seen by the example
182 in the report by Hagemann et al., which states that "biochar is produced from sustainably sourced biomass
183 and is used for non-oxidative applications in agriculture (e.g., in soil)" (Cox et al. 2012, Spokas et al. 2012,
184 Hagemann et al. 2018, Khalid et al. 2020, Lao and Mbega 2020, Shalini et al. 2020).

185

186 The feedstocks for biochar can be generally broken down into three major categories: forestry products,
187 agricultural and food products, and manures and sewage wastes. Biomass from forestry products does not

188   include harvesting trees for biochar production but is sourced from various forestry wastes. These wastes
189   are diverse and include bark, woodchips, waste wood in the form of unusable logs and branches, and
190   sawdust from lumber production (Verheijen et al. 2010, Cox et al. 2012, Anderson et al. 2013, Al-Wabel et
191   al. 2018, Ji et al. 2019, Khalid et al. 2020, Lao and Mbega 2020, Shalini et al. 2020). Forestry product wastes
192   may also be generated by the forest maintenance operation of removing undergrowth to promote forest
193   health and reduce the risk of forest fires (Anderson et al. 2013). Agricultural and food product feedstocks
194   include wastes from crop production (e.g., crop remnants, cobbs, stalks, straws, bagasse) and from food
195   processing (e.g., shells, husks, hulls, peels) (Verheijen et al. 2010, Cox et al. 2012, Spokas et al. 2012, Al-
196   Wabel et al. 2018, Oni et al. 2019, Wang J et al. 2019, Khalid et al. 2020, Lao and Mbega 2020, Nagula and
197   Ramanjaneyulu 2020, Shalini et al. 2020). Manures and sewage wastes can be sourced from agricultural
198   livestock production and from treated human sewage sludge (Cox et al. 2012, Spokas et al. 2012, Al-Wabel
199   et al. 2018, Oni et al. 2019, Lao and Mbega 2020, Shalini et al. 2020). Livestock manures have been reported
200   to have many sources, including, poultry, cattle, pigs, goats, and horses from both conventional and
201   organic agricultural sources (Cox et al. 2012, Spokas et al. 2012, Al-Wabel et al. 2018, Oni et al. 2019, Shalini
202   et al. 2020).
203
204   **Properties of the Substance:**
205   Biochar is a solid that is generally black or charred and can be found in many forms, such as chips, pellets,
206   and dust (Sohi et al. 2009, Verheijen et al. 2010, Cox et al. 2012, Biochar Industries 2013, Stormwater
207   BIOCHAR 2018, Aries GREEN 2019). The exact composition of the substance varies, although the bulk is
208   often elemental carbon in the form of graphene and various aromatic compounds (Sohi et al. 2009,
209   Verheijen et al. 2010, Lehmann and Joseph 2015). The pH of biochar typically ranges from neutral to basic
210   (Sohi et al. 2009, Verheijen et al. 2010, Cox et al. 2012, Biochar Industries 2013, Qian et al. 2015, Stormwater
211   BIOCHAR 2018, Aries GREEN 2019, Tenic et al. 2020). Biochar has been noted to have sorption and cation
212   exchange capacity (CEC) due to the presence of organic functional groups on the surface of the substance,
213   which selectively bind to positively charged ions (cations) (Verheijen et al. 2010). The porous nature of
214   biochar also provides a large surface area for adsorption of ions and other compounds and a means to hold
215   water and facilitate microbial growth (Sohi et al. 2009, Verheijen et al. 2010, Cox et al. 2012, Agrafioti et al.
216   2013, Lehmann and Joseph 2015, Tenic et al. 2020). General biochar properties are summarized below in
217   Table 3.
218
219

Table 3. Properties of biochar

Appearance	Black or charred pellets, chips, or dust
CAS No. (Carbon)	7440-44-0
pH	4.81–11, mean 8.1
Water solubility	Not soluble
Specific gravity	0.25–0.65
Odor	Odorless
Carbon: Nitrogen (C:N) ratio	7–600, mean 61

220   Sources: Verheijen et al. 2010, Cox et al. 2012, Spokas et al. 2012, Biochar
221   Industries 2013, Lehmann and Joseph 2015, Stormwater BIOCHAR 2018,
222   Aries GREEN 2019.
223
224   **Specific Uses of the Substance:**
225
226   Uses of biochar are summarized below. Additional information about each use is included in the section
227   titled Action of the Substance.
228
229   *Soil amendment*
230
231   Biochar has many applications as a soil amendment. There have been reports that biochar additions
232   enhance root growth due to improved soil aggregation and decreased soil density (Cox et al. 2012,
233   Lehmann and Joseph 2015, Tenic et al. 2020). The porous nature of biochar has been reported to improve
234   water retention in soils, reducing soil irrigation requirements (Cox et al. 2012, Obia et al. 2016, Wang D et

235   al. 2019, Tenic et al. 2020). The cation exchange capacity (CEC) of the substance improves bioavailability of
236   essential nutrients and prevents run-off of applied fertilizers (Singh et al. 2010, Van Zwieten et al. 2010c,
237   Cox et al. 2012, Wang J et al. 2019). The bioavailability of soil nutrients is further enhanced by the basic
238   nature of the substance, which helps to raise the pH of acidic soils (Cox et al. 2012). The porous nature of
239   biochar and improved bioavailability of soil nutrients generally result in growth of microbial communities
240   (Cox et al. 2012, Tenic et al. 2020). The combined effects of biochar as a soil amendment have been reported
241   to improve crop resiliency and reduce disease (Cox et al. 2012, Tenic et al. 2020).

243   *Soil remediation (decontamination of heavy metals and pesticides)*

245   Biochar has been studied as a means to decontaminate soils that have been polluted with heavy metals
246   (Park et al. 2011, Spokas et al. 2012, Hertsgaard 2014, Tenic et al. 2020). The sorbent nature of the substance
247   has been shown to reduce soil mobility and bioavailability of heavy metal pollutants, including copper
248   (Cu), cadmium (Cd), lead (Pb), arsenic (As), nickel (Ni), and zinc (Zn) (Renner 2007, Cao and Harris 2010,
249   Park et al. 2011, Ippolito et al. 2012, Agrafioti et al. 2013, Tenic et al. 2020). Biochar has also been reported to
250   remediate a variety of pesticides and herbicides. The sorption properties of biochar result in sequestration
251   of some pesticides, herbicides, antibiotics, and pharmaceutical compounds, which reduce their
252   bioavailability and uptake by plants and prevent leaching into water systems (Oni et al. 2019, Varjani et al.
253   2019, Khalid et al. 2020).

255   *Carbon sequestration*

257   As biomass (plants) grow, they absorb carbon dioxide (CO_2) from the atmosphere. Because biochar is
258   produced in a limited-oxygen environment, a minimal amount of carbon dioxide is release from the
259   biomass feedstock, especially when compared to a combustion reaction (in an oxygen-rich environment), of
260   which carbon dioxide is a major product (Sohi et al. 2009). The chemical and biological stability of the
261   carbon in biochar along with the limited release of carbon dioxide has made biochar a potential source of
262   long-term carbon sequestration (Verheijen et al. 2010, Kusmierz and Oleszczuk 2014, Lehmann and Joseph
263   2015, Hagemann et al. 2018). In addition to the carbon sequestration capability that biochar provides when
264   applied to soils, it has been reported as a concrete additive (Lehmann and Joseph 2015, Hagemann et al.
265   2018). If added to concrete, biochar would permanently sequester solid carbon from the atmosphere, while
266   the amount of cement and sand required for concrete production would be reduced (Gupta and Kua 2017,
267   Akhtar and Sarmah 2018, Hagemann et al. 2018, Shalini et al. 2020).

269   Additional information about the role of biochar in carbon sequestration is discussed in Evaluation
270   Question 9.

272   *Mitigation of greenhouse gas emissions*

274   The application of biochar has been reported to change the carbon (C) and nitrogen (N) metabolism cycle
275   within the soil (Singh et al. 2010). These metabolism changes result in decreased emissions of methane
276   (CH_4) and nitrous oxide (N_2O), which are more potent greenhouse gases than carbon dioxide (Singh et al.
277   2010, Verheijen et al. 2010, Zhang et al. 2010, Qian et al. 2015). The reduction of fertilizer run-off from over
278   application further reduces the formation and emission of nitrous oxide in soils (Qian et al. 2015).

280   Additional information about the role of biochar in the mitigation of greenhouse gas emissions is discussed
281   in Evaluation Question 9.

283   *Activated charcoal feedstock*

285   As discussed above in the section "Activated Charcoal vs Biochar," these two substances belong to the
286   same family of PCMs and have similar elemental compositions and chemical structures (Renner 2007, Cox
287   et al. 2012, Anderson et al. 2013, Verheijen et al. 2010, Hagemann et al. 2018). Because of biochar's similarity
288   in nature and production to activated charcoal, biochar can be activated, resulting in increased surface area
289   and sorbent capacity and leading to the formation of activated charcoal (Spokas et al. 2012, Qian et al.

290   2015). However, activated charcoal possesses increased sorbent capacity due to the increased surface area
291   from the activation process (USDA 2002, Marsh and Reinoso 2006, Hagemann et al. 2018).
292
293   *Adsorbent species*
294
295   While activated charcoal has a greater sorbent capacity than biochar, it has been reported to have
296   applications as an adsorbent species for purification purposes (Verheijen et al. 2010, Spokas et al. 2012,
297   Qian et al. 2015, Shalini et al. 2020). There have been some reports of biochar being used for water
298   purification; however, this use has limited applicability in this context due to the possibility of heavy metal
299   contaminants in some feedstocks (Lima and Marshall 2009, Spokas et al. 2012). Biochar has also been
300   reportedly used as an adsorbent in flue gas applications to remove mercury (Hg) and carbon dioxide
301   (Klasson et al. 2010, Spokas et al. 2012, Gonzalez et al. 2013, Hertsgaard 2014, Qian et al. 2015).
302
303   **Approved Legal Uses of the Substance:**
304   The NOP has defined biochar as "a biomass that has been carbonized or charred" and classified it as a non-
305   synthetic substance via guidance from NOP 5034-1 (NOP 2016a). Additionally, NOP stipulates that
306   "[biochar] sources must be untreated plant or animal material" and the "pyrolysis process must not use
307   prohibited additives" (NOP 2016a). However, the USDA organic regulations prohibit the use of non-
308   synthetic "ash from manure burning," at 7 CFR 205.602. The prohibition of biochar from manure burning, a
309   feedstock documented thoroughly in the literature, has resulted in ambiguity regarding whether biochar is
310   ever allowed for use in organic agriculture.
311
312   Additionally, the NOP has approved the use of activated charcoal as a "synthetic substance allowed for use in
313   organic livestock production," with the stipulation that it is produced "from vegetative sources," at 7 CFR
314   205.603. The USDA NOP has also approved the use of activated charcoal "from vegetative sources as a filtering
315   aid" in "processed products labeled as 'organic' or 'made with organic'" at § 205.605.
316
317   **Action of the Substance:**
318
319   *Soil amendment*
320
321   The porous nature of biochar results in its relatively low density (Verheijen et al. 2010, Lehmann and
322   Joseph 2015, Tenic et al. 2020). When biochar is combined with soil, the typical result is a less dense
323   mixture, which promotes root growth more effectively compared to compacted soil (Verheijen et al. 2010,
324   Zhang et al. 2010, Lehmann et al. 2011, Cox et al. 2012, Lehmann and Joseph 2015, Tenic et al. 2020).
325   However, given the range of types of biochar and application methods, it is also possible that the porous
326   substance is compacted by heavy machinery once in the soil, resulting in greater soil density (Verheijen et
327   al. 2010). Biochar also promotes root growth by improving soil aggregation through interactions of surface
328   functional groups with existing soil (Chan et al. 2003, Lehmann et al. 2011, Cox et al. 2012, Blanco-Canqui
329   2017, Verheijen et al. 2019, Tenic et al. 2020). The chemical and biological stability of biochar is likely to
330   contribute to long-term soil aggregation (Cox et al. 2012).
331
332   Biochar can affect the water retention of soils in both a positive and negative manner. Studies suggest that
333   water retention is influenced largely by the type of soil used rather than by the biochar (Uzoma et al. 2011,
334   Cox et al. 2012, Bayabil et al. 2015). Coarse, textured, or sandy soils typically show increased water
335   retention capacity after biochar incorporation, while clay soils show neither an increase nor a decrease in
336   water retention capacity (Verheijen et al. 2010, Obia et al. 2016, Blanco-Canqui 2017, Wang D et al. 2019,
337   Tenic et al. 2020). Improvements in the water retention of soils is due to the porous nature of biochar and
338   the reduced density of soils that include biochar (Asai et al. 2009, Verheijen et al. 2010, Uzoma et al. 2011,
339   Cox et al. 2012, de Jesus Duarte et al. 2019, Verheijen et al. 2019, Tenic et al. 2020). Biochar surface area is an
340   important factor in water retention; biochar that has been produced at higher temperatures (500–700 ˚C)
341   have an increased surface area and drive off hydrophobic functional groups as volatile matter in the
342   production process (Verheijen et al. 2010, Kinney et al. 2012, Suliman et al. 2017, Tenic et al. 2020). When
343   considering biochar feedstocks, wood-based biochar tends to result in larger pore sizes than those based in

344   manure or wastewater sludge, making them more effective when applied for water retention purposes
345   (Verheijen et al 2010, Tenic et al. 2020).
346
347   Biochar has been reported to enhance the CEC of applied soils (Van Zwieten et al. 2010c, Cox et al. 2012,
348   Bayabil et al. 2015, Lehmann and Joseph 2015, Qian et al. 2015, Wang J et al. 2019, Tenic et al. 2020).
349   Functional groups on the surface of the substance bind positively charged ions (cations)— for example,
350   potassium (K^+), magnesium (Mg^{2+}), and calcium (Ca^{2+})—through electrostatic attractions (Cox et al. 2012,
351   Jiang et al. 2019, Tenic et al. 2020). The ability to retain these nutrients in the soil has been proposed as one
352   of the primary crop growth methods associated with biochar. There have also been reports of increases
353   CEC enhancement over time; this is likely due to the oxidation of the biochar surface, which increases the
354   number of functional groups and therefore nutrient binding sites (Liang et al. 2006, Cheng et al. 2008,
355   Cheng and Lehmann 2009, Verheijen et al. 2010, Cox et al. 2012). The nutrient binding ability of biochar
356   prevents the loss of water-soluble nutrients as run-off (Jiang et al. 2019, Tenic et al. 2020).
357
358   Biochar adds nutrients to the soil. Despite the stability of the carbon framework of the biochar solid, the
359   potassium and nitrate contents of the substance is readily available for plant uptake (Cox et al. 2012,
360   Lehmann and Joseph 2015). Other nutrient bioavailability varies depending on the feedstock and
361   production conditions of the biochar and the properties of the soil (Joseph et al. 2010, Cox et al. 2012,
362   Lehmann and Joseph 2015). In terms of biochar's nitrogen content, bioavailability depends on whether the
363   element has been incorporated into aromatic rings (heteroatoms are not incorporated into aromatic ring
364   structures), which must be liberated by microbes prior to plant uptake (Knicker et al. 1996, Verheijen et al.
365   2010, Liu et al. 2018, Tenic et al. 2020). The limited bioavailability of some nutrients in biochar has resulted
366   in its use as a slow-release fertilizer (Verheijen et al. 2010, Qian et al. 2015, Tenic et al. 2020). Biochar that is
367   produced from manure and grass feedstocks tend to be more nutrient rich than other feedstocks (Chan et
368   al. 2008, Park et al. 2011, Cox et el. 2012, Spokas et al. 2012). Biochar that is produced at lower temperatures
369   (<500 °C) also tend to have higher nutrient content and nutrients that are more bioavailable (Verheijen et al.
370   2010, Xiao et al. 2018, Tenic et al. 2020)
371
372   Though the pH of biochar varies depending on feedstock and production conditions, most are basic (pH >
373   7), as shown in Table 3 (Verheijen et al. 2010, Cox et al. 2012, Spokas et al. 2012, Qian et al. 2015). The
374   application of biochar to soil has generally been reported to have a liming effect, which can be beneficial to
375   acidic soils (Verheijen et al. 2010, Park et al. 2011, Cox et al. 2012, Spokas et al. 2012). Moreover, the
376   resulting basic pH increases the solubility of nutrients (e.g., potassium [K], sodium [Na], nitrogen [N],
377   phosphorous [P]) (Park et al. 2011, Cox et al. 2012, Spokas et al. 2012, Tenic et al. 2020). The increased soil
378   pH also reduces the water solubility and bioavailability of aluminum (Al), which is toxic to plants (Tenic et
379   al. 2020). Biochar from manures tend to have a higher pH than other feedstocks and have been reported to
380   better amend acidic soils (Verheijen et al. 2010, Tenic et al. 2020).
381
382   The introduction of biochar has been reported to affect the microbial communities present in the soil in
383   both positive and negative manners, although the application of biochar generally results in a positive
384   outcome for microbial growth (Cox et al. 2012, Lehmann and Joseph 2015). Application of biochar can have
385   a "priming" effect on microbial growth that is either positive or negative (Verheijen et al. 2010, Cox et al.
386   2012, Tenic et al. 2020). Priming occurs with an initial increase or decrease in microbial growth or activity
387   and is due to changes to the physical and chemical properties of the soil, specifically the availability of
388   nutrients (Cox et al. 2012). Grass and manure feedstocks and biochar with low production temperatures
389   (<500 °C) typically result in positive priming due to their relatively high nutrient content and
390   bioavailability (Verheijen et al. 2010, Zimmerman et al. 2011, Tenic et al. 2020). Wood-based feedstocks and
391   biochar with high production temperatures (>500 °C) have been reported to produce negative priming due
392   to the relative deficiency of bioavailable nutrients and increased surface area to bond soil nutrients (Cross
393   and Sohi 2011, Tenic et al. 2020).
394
395   Despite the possible priming effects, biochar application generally results in long-term increases in the
396   population and activity of microbial communities (Verheijen et al. 2010, Tenic et al. 2020). These long-term
397   increases are reportedly due to the porous nature of biochar providing micro-environments that foster the

398 growth of microorganisms and protect them from predation (Pietikainen et al. 2000, Warnock et al. 2007,
399 Verheijen et al. 2010, Cox et al. 2012, Lehmann and Joseph 2015).
400
401 The combined effects of improved soil properties, nutrient bioavailability, water retention, immobilization
402 of toxic minerals, and microbial growth are proposed to be the reason for reported crop resilience (Qian et
403 al. 2015, Tenic et al. 2020). Adding to these effects are reports that biochar acts to deactivate pathogens (Cox
404 et al. 2012, Tenic et al. 2020). Researchers have proposed that pathogen protection may be the result of
405 specific microorganisms in the soil, although no definitive mechanism of protection has been widely
406 accepted (Graber et al. 2010, Tenic et al. 2020).
407
408 *Soil remediation (decontamination of heavy metals, pesticides)*
409
410 Biochar applied to soil remediation uses its CEC properties to sequester heavy metals, which exist as
411 cations in nature (Silberberg 2003, Park et al. 2011, Agrafioti et al. 2013, Qian et al. 2015, Oni et al. 2019). The
412 increased charge of these heavy metal ions results in an increase in electrostatic attraction with the biochar
413 surface, preventing the ions' mobility in the soil and therefore bioavailability to plants and microorganisms
414 (Atkins et al. 2008). However, the nature of biochar production results in high surface functional group
415 density at low production temperatures and high surface area at high production temperatures, both of
416 which are advantageous for the capture of heavy metal contaminants (Oni et al. 2019, Tenic et al. 2020).
417 Low temperature biochar has been reported to be more effective in the remediation of cadmium and lead,
418 while high temperature biochar has been shown to be more effective at capturing nickel and zinc
419 (Lomaglio et al. 2018, O'Connor et al. 2018, Tenic et al. 2020). While biochar has been shown to be a
420 successful means of immobilizing heavy metals in soil, its long-term capacity to retain these contaminants
421 in an immobile state has not been reported (Tenic et al. 2020). Moreover, while the immobilization of heavy
422 metals in biochar soils appears to be a beneficial outcome, it may also result in the localized accumulation
423 of pollutants over time (Verheijen et al. 2010).
424
425 There are many possible mechanisms for biochar to sequester pesticides, herbicides, antibiotics, and
426 pharmaceutical compounds, with the mode of action determined by the unique properties of the biochar
427 and the structure of the pesticide or herbicide (Oni et al. 2019, Khalid et al. 2020). Possible modes of
428 sequestration include adsorption (due to biochar's high surface area and presence of micropore structures),
429 CEC, Van der Waals interactions, and pi interactions (Oni et al. 2019, Khalid et al. 2020). Van der Waals
430 interactions are thought to be the predominant adsorption pathway in biochar produced at high
431 temperatures (Silberberg 2003, Tenic et al. 2020). High temperature biochar production maximizes surface
432 area and reduces the presence of functional groups, leaving a surface dominated by a network of bonds
433 throughout a network of elemental carbon (Tenic et al. 2020). The loss of organic functional groups reduces
434 polar intermolecular forces, which makes Van der Waals interactions the dominant force on the biochar
435 surface (Silberberg 2003, Oni et al. 2019). The CEC properties of biochar provide interactions with more
436 polar molecules for the sequestration of pesticides and herbicides through dipole interactions and
437 hydrogen bonding networks with organic functional groups (e.g., carboxylic acids and their derivatives,
438 amines) (Silberberg 2003, Timberlake 2016, Oni et al. 2019). The formation of aromatic structures during
439 biochar production allows pi-stacking and other pi interactions that contribute to the sequestration of
440 pesticides and herbicides that have aromatic rings in their structures (Oni et al. 2019, Khalid et al. 2020).
441
442 The effect of biochar on the biodegradation of pesticides and herbicides is unclear because of inconsistency
443 across literature reports (Luo et al. 2019, Oni et al. 2019, Varjani et al. 2019, Yavari et al. 2019, Khalid et al.
444 2020). The inconsistency in reports is likely due to the high variability across biochars due to the diversity
445 of feedstocks and production methods and individual environmental conditions (Khalid et al. 2020).
446 Biochar's ability to sequester organic pollutants (e.g., pesticides, herbicides) reduces its availability for
447 degradation by microorganisms (Oni et al. 2019, Varjnai et al. 2019, Khalid et al. 2020). However, increased
448 microbial activity associated with biochar application likely increases biodegradation of organic pollutants
449 that are not sequestered by biochar (Varjani et al. 2019, Khalid et al. 2020). The effect of biochar on the
450 degradation of organic pollutants is likely to vary due to the two opposing mechanisms of sequestration
451 versus enhanced microbial activity; and are likely to be dependent on the unique properties of the biochar,

452 the organic pollutant, and the environmental conditions determining whether rates of biodegradation are
453 increased or decreased (Khalid et al. 2020).
454
455 *Carbon sequestration*
456
457 Biochar production has been classified as carbon neutral or carbon negative (depending on production
458 conditions) since the carbon dioxide captured in the biomass during photosynthesis is sequestered as a
459 solid in biochar (Verheijen et al. 2010, Qian et al. 2015). The chemical and biological stability of the carbon
460 in biochar, along with the limited release of carbon dioxide, has made biochar a potential source of long-
461 term carbon sequestration (Verheijen et al. 2010, Lehmann and Joseph 2015, Hagemann et al. 2018).
462
463 Additional information about the role of biochar in carbon sequestration is discussed in Evaluation
464 Question 9.
465
466 *Mitigation of greenhouse gas emissions*
467
468 The incorporation of biochar is thought to reduce the availability of inorganic nitrogen sources, reducing
469 the rate of nitrogen cycling within the soil (Singh et al. 2010, Verheijen et al. 2010, Yao et al. 2010, Cox et al.
470 2012). Biochar has been shown to retain nitrogen in soils in the form of ammonia (NH_3) and ammonium
471 (NH_4^+), key components of fertilizers, reducing the amount of fertilizer required for growing crops and lost
472 to the environment via run-off (Clough and Condron 2012). The interactions of inorganic nitrogen sources
473 with biochar also reduce reactivity of ammonia and ammonium in soil, slowing down the nitrogen cycle
474 and reducing soil acidification and nitrous oxide (N_2O) emissions (Clough and Condron 2012, Tenic et al.
475 2020). Studies show that biochar produced at high temperatures (>500 °C) produce the most dramatic
476 improvements of ammonia and ammonium soil retention due to their increased surface areas (Asada et al.
477 2002, Clough and Condron 2012). There have also been reports of biochar's ability to bind nitrogen sources
478 may improve over time through oxidation of the surface via weathering processes (Lehmann et al. 2003,
479 Singh et al. 2010, Cox et al. 2012).
480
481 Additional information about the role of biochar in the mitigation of greenhouse gas emissions is discussed
482 in Evaluation Question 9.
483
484 **Combinations of the Substance:**
485 When used as a soil amendment, biochar can be combined with various fertilizers to enhance crop
486 productivity (Lehmann et al. 2003, Yamato et al. 2006, Steiner et al. 2007, Verheijen et al. 2010, Zhang et al.
487 2010, Cox et al. 2012). These fertilizers can range from nitrogen and phosphorous enhancers to manure and
488 compost (Cox et al. 2012, Spokas et al. 2012, Kalus et al. 2019). The CEC property of biochar when
489 combined with fertilizers has been reported to slow the release of nutrients in the soil and reduce mineral
490 run-off (Verheijen et al. 2010, Spokas et al. 2012, Hagemann et al. 2018, Kalus et al. 2019). Biochar from
491 different feedstocks and/or production conditions may also be combined to better suit the application (e.g.,
492 to address specific deficiencies of the soil) (Jiang et al. 2019, Tenic et al. 2020).
493

Status

495
496 **Historical Use:**
497 Although the term "biochar" is relatively new, charcoal material has a long tradition of agricultural use,
498 dating back thousands of years. The most prominent example in the literature is the "Terra Preta" of the
499 Amazon, which dates back over 10,000 years (Glaser et al. 2000, Glaser et al. 2001, Renner 2007, Hagemann
500 et al. 2018). There have also been documented applications of charcoal in Japan and Europe (Renner 2007,
501 Ogawa and Okimori 2010, Verheijen et al. 2010, Spokas et al. 2012, Tenic et al. 2020). In these instances,
502 charcoal was incorporated with surrounding soil from Anthrosols (man-made soils), which covered an
503 estimated 10,000–21,000 km² (Blume and Leinweber 2004, Woods et al. 2006, Verheijen et al. 2010). These
504 Anthrosols exist at depths up to 1 m and are typically found in nutrient-deficient, dry, and sandy soils near
505 permanent human settlements (Verheijen et al. 2010).
506

507 **Organic Foods Production Act, USDA Final Rule:**
508 Biochar is not listed in the Organic Foods Production Act of 1990 (OFPA) or the USDA organic regulations at 7
509 CFR part 205. The NOP has defined biochar as "a biomass that has been carbonized or charred" and classified it
510 as a non-synthetic substance in NOP 5034-1 (NOP 2016a). Additionally, the NOP stipulates that biochar "sources
511 must be untreated plant or animal material," and the "pyrolysis process must not use prohibited additives"
512 (NOP 2016a). However, the NOP has prohibited the use of "ash from manure burning" at 7 CFR 205.602.
513
514 The origin of the prohibition of "ash from manure burning" can be traced to an NOSB meeting in April
515 1995 (NOSB 1995, NOSB 2019). However, the details regarding the nature of this prohibition are not
516 included in the reported NOSB minutes from the meeting, and the full description from the minutes on the
517 subject are limited to the description "Determined to be non-synthetic. Merrigan moved and Sligh
518 seconded a motion to prohibit manure ash for use in organic crop production. Passed unanimously"
519 (NOSB 1995). Following the NOSB's initial recommendation to prohibit ash from manure burning the
520 prohibition was renewed at NOSB sunset recommendations in 2005, 2010, and 2015 (NOSB 2005, NOSB
521 2010, NOSB 2015, NOSB 2019).
522
523 In 2016 the NOSB issued a recommendation to keep the NOP's prohibition of ash from manure burning due to
524 the removal of carbon and nitrogen sources from the resulting ash product through combustion reactions (NOSB
525 2016). This NOSB recommendation cited that prohibition should be maintained since "burning removes carbon
526 and nitrogen from the final ash product and lessens its soil-building value" (NOSB 2016). Additionally, the NOSB
527 recommendation stated that "utilizing burning as a method to recycle millions of pounds of excess poultry
528 manure inadvertently supports the business of CAFOs (concentrated animal feeding operations) by creating an
529 organic industry demand for ash" (NOSB 2016). The NOP further clarified the following in this prohibition: "For
530 the purposes of classification, pyrolysis may be treated as equivalent to burning or combustion" (NOP 2016b).
531
532 While there are distinct differences in combustion and pyrolysis, both processes result in the loss of organic
533 carbon and nitrogen material from the original feedstock. However, the difference in oxygen content
534 results in combustion and pyrolysis having different products. The oxygen-rich environment required for
535 combustion reactions produces oxidized oxygen and nitrogen atoms, predominantly in the form of small,
536 gaseous molecules (e.g., CO, CO_2, NO, NO_2) (Silberberg 2003, Timberlake 2015). The oxygen-deficient
537 environment required for pyrolysis also results in carbon and nitrogen losses through the formation of
538 liquid and gas products (e.g., hydrocarbons such as methane, ethane, etc.) (Verheijen et al. 2010). However,
539 pyrolysis produces a larger percentage of solid products (biochar) and therefore a larger percentage of the
540 original carbon and nitrogen content of the biomass than combustion processes (ash as the powder residue
541 left after a material is burned) (Demibras and Arin 2002, Mohan et al. 2006, Verheijen et al. 2010,
542 Bridgewater 2012, Cox et al. 2012, Spokas et al. 2012, Lehmann and Joseph 2015, Qian et al. 2015,
543 Hagemann et al. 2018).
544
545 Activated charcoal is listed in 7 CFR part 205 as approved for use at 7 CFR 205.603 as a "synthetic substance
546 allowed for use in organic livestock production" with the stipulation that it is produced "from vegetative
547 sources." Activated charcoal also appears "from vegetative sources as a filtering aid" in "processed products
548 labeled as 'organic' or 'made with organic'" at § 205.605.
549
550 **International**
551
552 **Canadian General Standards Board Permitted Substances List**
553
554 Biochar is listed in the Canadian General Standards Board Permitted Substances List in "Table 4.2 – Soil
555 amendments and crop nutrition" as "produced through pyrolysis of forestry by-products which have not
556 been treated with or combined with prohibited substances," with the notation that "recycled biochar from
557 contaminated remediation sites is prohibited."
558
559 **CODEX Alimentarius Commission, Guidelines for the Production, Processing, Labelling and Marketing**
560 **of Organically Produced Foods (GL 32-1999)**
561

562 Biochar is not listed in the CODEX, however, "wood ash and wood charcoal" are listed in "Table 1:
563 Substances for use in soil fertilizing and conditioning" with the stipulation that the charcoal must be
564 produced "from wood not chemically treated after felling."
565
566 **European Economic Community (EEC) Council Regulation, EC No. 834/2007 and 889/2008**
567
568 Biochar is not listed in the EEC EC No. 834/2007 or 889/2008.
569
570 **Japan Agricultural Standard (JAS) for Organic Production**
571
572 Biochar is not listed in the JAS; however, charcoal is listed in "Attached Table 1 – Fertilizers and soil
573 improvement substances" in JAS notifications No. 1605 and No. 1608 with the limitation that the charcoal
574 must be "derived from natural sources or natural sources without the use of chemical treatment."
575
576 **International Federation of Organic Agriculture Movements (IFOAM)**
577
578 Biochar is not listed in IFOAM. However, "wood charcoal" is listed in "Appendix 2: Fertilizers and soil
579 conditioners" as allowed "if not chemically treated."
580

581 **Evaluation Questions for Substances to be used in Organic Crop or Livestock Production**

582
583 **Evaluation Question #1: Indicate which category in OFPA that the substance falls under: (A) Does the**
584 **substance contain an active ingredient in any of the following categories: copper and sulfur**
585 **compounds, toxins derived from bacteria; pheromones, soaps, horticultural oils, fish emulsions, treated**
586 **seed, vitamins and minerals; livestock parasiticides and medicines and production aids including**
587 **netting, tree wraps and seals, insect traps, sticky barriers, row covers, and equipment cleansers? (B) Is**
588 **the substance a synthetic inert ingredient that is not classified by the EPA as inerts of toxicological**
589 **concern (i.e., EPA List 4 inerts) (7 U.S.C. § 6517[c][1][B][ii])? Is the synthetic substance an inert**
590 **ingredient which is not on EPA List 4, but is exempt from a requirement of a tolerance, per 40 CFR part**
591 **180?**
592
593 Biochar has been categorized as a non-synthetic substance by the NOP and is therefore an allowed
594 substance per OFPA. Biochar itself is not produced in nature but rather results from the thermal
595 degradation of biomass (e.g., crop residues, wood products, manures, bones, etc.). The thermal degradation
596 of biomass produces chemical changes in the biochar product. The NOP has classified transformations of
597 "heating or burning of biological matter (e.g., plant or animal material)" as "a natural process that does not
598 result in the classification of ash as synthetic" under the guidance for classification of materials (NOP
599 2016c). Additionally, the NOP has ruled that "pyrolysis (i.e., high temperature decomposition of
600 substances in the absence of oxygen) may be treated as equivalent to burning or combustion" (NOP 2016c).
601
602 Biochar does not contain any active ingredients listed in (A). However, since the substance is produced
603 from a variety of natural feedstocks, it may contain small amounts of sulfur compounds and minerals
604 (Anatal and Gronli 2003, Demirbas 2004, Verheijen et al 2010, Cox et al. 2012, Lehmann and Joseph 2015,
605 Abd El-Mageed et al. 2020). The mineral content of biochar is present in the form of ash. Biochar makeup is
606 varied due to the range of feedstocks and processing conditions, and the total mineral ash within biochar
607 has been reported to range from 0.27% to 11.2% of the substance (Anatal and Gronli 2003, Verheijen et al.
608 2010, Lehman and Joseph 2015).
609
610 Biochar is not listed by the EPA as an inert ingredient of minimal concern (List 4), nor is it in 40 CFR part
611 180. Activated charcoal that "meets specifications in the Food Chemical Codex" is listed by the EPA as an
612 "inert ingredient used in pre-and post-harvest" with "exemptions from the requirement of a tolerance" at
613 40 CFR 180.910.
614
615 **Evaluation Question #2: Describe the most prevalent processes used to manufacture or formulate the**
616 **petitioned substance. Further, describe any chemical change that may occur during manufacture or**

617 **formulation of the petitioned substance when this substance is extracted from naturally occurring plant,**
618 **animal, or mineral sources (7 U.S.C. § 6502[21]).**
619
620 There are several processes of producing biochar, and within these are many possible production
621 conditions (Verheijen et al. 2010, Cox et al. 2012). Among these is pyrolysis, the chemical decomposition of
622 organic substances by heating in the absence of oxygen. Pyrolysis is the most common production process
623 and has been optimized for maximum biochar yield (Verheijen et al. 2010, Cox et al. 2012, Qian et al. 2015,
624 Hagemann et al. 2018, Tenic et al. 2020). However, there are other processes that produce biochar through a
625 similar mechanism, but with different conditions (Cox et al. 2012). These processes most frequently differ
626 in terms of applied temperatures and residence times and include torrefaction and gasification (Cox et al.
627 2012). Additionally, all these processes may be completed at a stationary plant for large-scale production
628 (open production) or on site for small-scale production (closed production) (Verheijen et al. 2010). The
629 production method is dependent on both the availability of production technology (e.g., open vs. closed
630 production), the feedstock, and the application for the biochar product.
631
632 All three processes result in the formation of multiple products, which are broadly categorized as biochar
633 (solid products), bio-oil (liquids), and syngas (gases) (Verheijen et al. 2010, Cox et al. 2012, Hagemann et al.
634 2018, Tenic et al. 2020). The syngas that is produced during biochar production is primarily made up of
635 small hydrocarbons (e.g., methane [CH_4], ethane [C_2H_6], etc.); it also contains residual carbon dioxide and
636 steam and is flammable (Verheijen et al. 2010). Bio-oil is primarily made up of larger hydrocarbons and tars
637 (Verheijen et al. 2010). Syngas is typically collected and condensed into an oil/tar residue and combined
638 with bio-oil products. The mixture is then burned as combustion fuel to power the pyrolysis process, and
639 in some cases, produce electricity (Verheijen et al. 2010). This recycling of products helps to minimize
640 pyrolysis costs associated with fuel and carbon emissions (Verheijen et al. 2010). The ratio of these products
641 is dependent on the feedstock material and production conditions (Verheijen et al. 2010, Cox et al. 2012).
642
643 *Pyrolysis*
644
645 Pyrolysis is the traditional method of biochar and charcoal production, and modern methods produce the
646 greatest yields of biochar compared to liquid and syngas (Verhijen et al. 2010, Cox et al. 2012). Pyrolysis is
647 also the most common method of biochar production, and changes to production conditions result in
648 several subcategories of the process that vary based on applied temperatures and residence times
649 (Verheijen et al. 2010, Cox et al. 2012).
650
651   Traditional pyrolysis
652
653 Charcoal production was first documented over 5,500 years ago when it was used in the production of
654 bronze alloys (Earl 1995). In traditional pyrolysis methods, biomass materials typically consisted of wood
655 products and animal bones and were prepared at temperatures reaching approximately 400 °C with
656 residence times ranging from hours to days (Verheijen et al. 2010, Cox et al. 2012, Spokas et al. 2012).
657 Traditional pyrolysis methods typically yield equal proportions of biochar, bio-oil, and syngas (Cox et al.
658 2012). However, unlike modern fast and slow pyrolysis methods, traditional pyrolysis results in bio-oil and
659 syngas products that are mostly lost to the environment (Verheijen et al. 2010).
660
661   Slow Pyrolysis
662
663 Compared to modern fast pyrolysis, slow pyrolysis more closely represents traditional biochar production
664 methods. In slow pyrolysis applications, the temperature ranges from 300 to 500 °C, with typical residence
665 times of 30 to 90 minutes (Brandli et al. 2007, Meyer et al. 2011, Cox et al. 2012). Slow pyrolysis production
666 requires minimal pre-production treatment of feedstocks and is amenable to large material (Cox et al.
667 2012).
668
669 Because slow pyrolysis maximizes yield of biochar while minimizing potential loss of byproducts, it is the
670 most common method of biochar production (Verhijen et al. 2010, Cox et al. 2012, Qian et al. 2015, Tenic et
671 al. 2020). Slow pyrolysis has also been called "carbonization" due to the relatively large amount of solid

672 carbon it produces (Verheijen et al. 2010, Hagemann et al. 2018). Biochar produced at low temperatures
673 (300–400 ˚C) will result in incomplete carbonization of the feedstock and will have relatively small pores
674 and surface area (Cox et al. 2012, Lehmann and Joseph 2015). The pH of biochar produced at low
675 temperatures tends to be more acidic due to the greater retention of organic functional groups compared to
676 biochar produced using higher temperature methods (Lehmann and Joseph 2015, Tenic et al. 2020).
677
678 Biochar from slow pyrolysis often has increased CEC properties due to its retention of organic functional
679 groups. The enhanced CEC in slow pyrolysis biochar is useful for applications involving increased nutrient
680 retention or for soil remediation (Silberberg 2003, Park et al. 2011, Cox et al. 2012, Agrafioti et al. 2013, Qian
681 et al. 2015, Obia et al. 2016, Wang D et al. 2019, Tenic et al. 2020).
682
683   Fast pyrolysis
684
685 Fast pyrolysis differs from slow pyrolysis in production conditions and also has different requirement for
686 pre-production treatments (Verheijen et al. 2010, Cox et al. 2012). Fast pyrolysis uses higher temperatures
687 (450–800 ˚C), faster heating rates, and shorter residence times (<30 seconds) than other pyrolysis methods
688 (Cox et al. 2012, Spokas et al. 2012, Hagemann et al. 2018). These conditions result in the following pre-
689 production requirements: feedstocks must be both reduced to small particle size and have a moisture
690 content less than 10%. These things are necessary for shorter residence times (Verheijen et al. 2010, Cox et
691 al. 2012).
692
693 The increased temperature and heating rate characteristic of fast pyrolysis result in bio-oil as the primary
694 product; therefore, biochar production is minimized (Qian et al. 2015, Tenic et al. 2020). The biochar that is
695 produced tends to be of increased porosity and surface area due to the increased temperature and pressure
696 of the production conditions (Cox et al. 2012). The pH of fast pyrolysis biochar tends to be more basic than
697 biochars produced at lower temperatures due to the volatilization of acidic functional groups within the
698 biomass (Yuan et al. 2011, Dai et al. 2014, Lehmann and Joseph 2015, Tenic et al. 2020).
699
700 Biochar from fast pyrolysis has increased surface area compared to biochar produced through other
701 production methods. The high surface area of fast pyrolysis biochar has applications involving increased
702 water retention (Asai et al. 2009, Verheijen et al. 2010, Uzoma et al. 2011, Cox et al. 2012, de Jesus Duarte et
703 al. 2019, Verheijen et al. 2019, Tenic et al. 2020). Additionally, the high pH of fast pyrolysis biochar has
704 applications for acidic soils due to both its liming effects and ability to improve nutrient retention in acidic
705 environments (Verheijen et al. 2010, Park et al. 2011, Cox et al. 2012, Spokas et al. 2012, Qian et al. 2015,
706 Tenic et al. 2020).
707
708 *Torrefaction*
709
710 The process of torrefaction utilizes the lowest temperatures (<300 ˚C) of all biochar production methods
711 (Cox et al. 2012, Spokas et al. 2012, Hagemann et al. 2018). The low temperatures used in torrefaction result
712 in biochars with relatively high oxygen:carbon ratios (0.4-0.6) and lower aromatic character than chars
713 produced via other methods (Spokas et al. 2012, Wang J et al. 2019).
714
715 The low temperature of the torrefaction process typically results in the highest yields of solid products and
716 is often used to increase the density of biomass for soil applications (Spokas et al. 2012). The torrefaction
717 method is also used as an intermediate step for the production of activated charcoal (Wang J et al. 2019).
718
719 *Gasification*
720
721 Gasification processes produce biochar as a byproduct and are optimized for the transformation of biomass
722 into syngas (Hagemann et al. 2018). Gasification is primarily used for energy and electricity production,
723 rather than agricultural applications or carbon sequestration (Hagemann et al. 2018). Gasification uses
724 higher temperatures (>800 ˚C) than other biochar production methods and typically has short residence
725 times (seconds to minutes) (Spokas et al. 2012, Hagemann et al. 2018).
726

727 A summary of the production conditions and product ratios of the prominent means of biochar production
728 are listed below in Table 4.
729
730   **Table 4. Processes for the production of biochar: products and properties**

Process	Temperature range (℃)	Heating rate (℃/s)	Residence time	Biochar %	Bio-oil %	Syngas %
Torrefaction	< 300	< 1	hours	40–90	0–5	10–60
Traditional pyrolysis	~ 400	variable	hours to days	30	35	35
Slow pyrolysis	300–500	0.1–100	30–90 minutes	15–40	0–55	20–70
Fast Pyrolysis	450–800	10–1000	< 30 seconds	10–30	50–75	5–15
Gasification	> 800	variable	seconds to minutes	0–15	5	> 85

731 Sources: Demibras and Arin 2002, Mohan et al. 2006, Verheijen et al. 2010, Bridgewater 2012, Cox et al.
732 2012, Spokas et al. 2012, Lehmann and Joseph 2015, Qian et al. 2015, Hagemann et al. 2018.
733
734 **Evaluation Question #3: Discuss whether the petitioned substance is formulated or manufactured by a**
735 **chemical process or created by naturally occurring biological processes (7 U.S.C. § 6502(21)).**
736
737 Biochar is known in nature primarily as the product of forest fires (Verheijen et al. 2010, Wang J et al. 2019).
738 However, nearly all biochar is produced by the thermochemical degradation of biomass in the absence of
739 oxygen, as discussed in Question 2 (Verheijen et al. 2010, Cox et al. 2012, Qian et al. 2015, Hagemann et al.
740 2018, Tenic et al. 2020). Biochar is produced through various biomass feedstocks that are created through
741 naturally occurring biological processes.
742
743 **Evaluation Question #4: Describe the persistence or concentration of the petitioned substance and/or its**
744 **by-products in the environment (7 U.S.C. § 6518(m)(2)).**
745
746 As discussed previously in the section "Composition of the Substance," biochar is not a uniform product; it
747 is greatly diverse due to variations in feedstocks and production conditions (Verhijen et al. 2010, Cox et al.
748 2012, Lehmann and Joseph 2015, Hagemann et al. 2018, Tenic et al. 2020). However, the primary
749 component of most biochar is in fixed carbon, found in the form of graphene and aromatic molecules (Sohi
750 et al. 2009, Verheijen et al. 2010, Lehmann and Joseph 2015). These compounds are highly
751 thermodynamically stable, making them resistant to chemical and biological decomposition (Cox et al.
752 2012). Due to the stability of its bulk component, biochar is long-lived in the environment, with persistence
753 in the order of hundreds to thousands of years (Cox et al. 2012, Tenic et al. 2020).
754
755 However, other components of biochar have much shorter lifetimes in the environment. These include
756 some of the stable aromatic components (polycyclic aromatic hydrocarbons [PAH]), which have been
757 reported to be removed from biochar-amended soils 3.5–35 months after application (Rombola et al. 2015,
758 Kusmierz et al. 2016, Wang J et al. 2019). These compounds may also be removed through aging or drying
759 processes, which have been reported to greatly reduce or eliminate PAH content from the treated biochar
760 (Koltowski and Oleszczuk 2015, Oleszczuk and Koltowski 2018, Wang J et al. 2019).
761
762 The mineral content of biochar includes potassium (K), phosphorus (P), and nitrogen (N) (Tenic et al.
763 2020). Potassium, phosphorous, and nitrogen in the form of nitrates are readily available for plant uptake
764 (Cox et al. 2012, Lehmann and Joseph 2015). Nitrogen bioavailability from other, non-nitrate, sources is
765 dependent on whether the nitrogen has been incorporated as a heteroatom in aromatic structures and must
766 be liberated by microbes prior to plant uptake (Knicker et al. 1996, Verheijen et al. 2010, Liu et al. 2018,
767 Tenic et al. 2020). Other nutrient bioavailability varies depending on the feedstock and production
768 conditions of the biochar and the properties of the soil (Joseph et al. 2010, Cox et al. 2012, Lehmann and
769 Joseph 2015).

770
771 **<u>Evaluation Question #5:</u> Describe the toxicity and mode of action of the substance and of its**
772 **breakdown products and any contaminants. Describe the persistence and areas of concentration in the**
773 **environment of the substance and its breakdown products (7 U.S.C. § 6518(m)(2)).**
774
775 Biochar may contain toxic substances, depending on the feedstock and production conditions. Toxic
776 substances that have been linked to biochar include polycyclic aromatic hydrocarbons (PAH), which are
777 typically formed using high-temperature production methods and heavy metals that are typically carried
778 over from the feedstock (Park et al. 2011, Spokas et al. 2012, Kusmierz and Oleszczuk 2014, Wang J et al.
779 2019).
780
781 *Polycyclic aromatic hydrocarbons (PAH)*
782
783 Biochar production conditions also result in the formation of polycyclic aromatic hydrocarbons (PAH),
784 some of which have been classified as persistent carcinogens (Verheijen et al. 2010, Cox et al. 2012,
785 Kusmierz and Oleszczuk 2014, Grimmer 2018, Wang J et al. 2019). These compounds are formed at
786 elevated temperatures by the degradation of biomass through dealkylation, dehydrogenation, cyclization,
787 aromatization, and radical reaction mechanisms (Kusmierz and Oleszczuk 2014). PAH content has been
788 reported to vary widely in biochars based on feedstock and production conditions (Fagernas et al. 2012,
789 Kusmierz and Oleszczuk 2014, Wang J et al. 2019). Studies have shown that PAH concentrations in biochar
790 tend to increase with higher production temperatures and longer residence times (Verheijen et al. 2010,
791 Wang J et al. 2019). A 2019 review found that when biochar was produced at temperatures below 200 ˚C,
792 none of the biochar exhibited PAH concentrations that exceeded standard industry thresholds; however, at
793 temperatures above 600 ˚C, 83% of the biochar exceeded these thresholds (Ledesma et al. 2002, Wang J et al.
794 2019).
795
796 PAH concentrations reportedly reduced over time and been removed from biochar-amended soils 3.5–35
797 months after application (Rombola et al. 2015, Kusmierz et al. 2016, Wang J et al. 2019). These compounds
798 may also be removed through aging or drying processes, which have been reported to greatly reduce or
799 eliminate PAH content in aged and dried biochar (Koltowski and Oleszczuk 2015, Oleszczuk and
800 Koltowski 2018, Wang J et al. 2019).
801
802 There have been reports of bio-accumulated PAH in food crops that were grown in biochar-amended soils
803 (Kahn et al. 2015, Wang et al. 2018, Wang J et al. 2019). PAH concentration in food crops varies based on
804 crop type, although accumulation has been reported in wheat, rice, leafy vegetables, root vegetables (Wang
805 J et al. 2019). While sorbent capacity of biochar prevents PAHs from leaching into surrounding water
806 systems, it also makes the contaminants available for plant uptake (Wang J et al. 2019). Additionally,
807 organic acids in the soil and excreted from the roots enhances the desorption of PAHs from biochar,
808 facilitating their uptake and accumulation in plants (Jones 1998, Ling et al. 2015, Ren et al. 2018, Wang J et
809 al. 2019). The concentrations of PAH accumulated in food crops has resulted in some portion of several
810 crops (up to 14% of those in the study) being classified as "low risk," according to guidelines set forth by
811 the United States Environmental Protection Agency (EPA), and poses the greatest biochar risk to the
812 general population (Wang J et al. 2019).
813
814 *Heavy metal contamination*
815
816 Some biomass feedstocks may be contaminated with heavy metals, which are more prevalent in waste
817 sludge and manure (Veeken and Hamelers 2002, Park et al. 2011, Cox et al. 2012, Agrafioti et al. 2013,
818 Varjani et al. 2019). These feedstocks have been reported to contain chromium (Cr), lead (Pb), copper (Cu),
819 and nickel (Ni), which are retained in the solid biochar product (Agrafioti et al. 2013). However, biochar
820 also has applications for remediating heavy metal contamination of soils, as discussed in the "Specific Uses
821 of the Substance," and "Action of the Substance" sections. The CEC properties of biochar result in the
822 sequestration of heavy metals through electrostatic binding interactions, which reduce the mobility and
823 bioavailability of heavy metals in soil (Silberg 2003, Atkins et al. 2008, Park et al. 2011, Agrafioti et al.
824 2013, Qian et al. 2015). Studies have shown that heavy metals are retained in the biochar, and their release

825 into the environment is reduced due to the pyrolysis process (Hwang et al. 2007, He et al. 2011, Agrafioti et
826 al. 2013, Kalus et al. 2019, Lao and Mbega 2020). Moreover, the bioavailability of heavy metals in biochar is
827 reduced when increased production temperatures are used (Lao and Mbega 2020, Tenic et al. 2020). There
828 have also been reports that co-pyrolysis of a feedstock potentially contaminated by heavy metals with a
829 non-contaminated feedstock reduces mobility of heavy metals in the biochar product (Wang et al. 2020).
830 Wood-based feedstocks have been reported to be especially effective for co-pyrolysis of potentially
831 contaminated materials due to their high lignin content, which has been associated with high-surface-area
832 biochar (Wang et al. 2020).

833

834 However, while the immobilization of heavy metals in biochar soils appears to be a beneficial outcome, it
835 may also result in the localized accumulation of pollutants over time (Verheijen et al. 2010). Furthermore,
836 long-term retention in biochar is unknown (Tenic et al. 2020).

837

838 **Evaluation Question #6: Describe any environmental contamination that could result from the**
839 **petitioned substance's manufacture, use, misuse, or disposal (7 U.S.C. § 6518(m)(3)).**

840

841 As described in the "Source or Origin of the Substance" section, biochar feedstocks are sourced as wastes
842 from several industries. Biomass used in the production of biochar is derived from wastes from forestry
843 products, food and agricultural products, and manures and treated sewage. Therefore, biochar production
844 does not contribute to environmental harvesting of biomass.

845

846 Biochar has the potential for environmental contamination at several stages. The production of biochar also
847 produces bio-oil and syngas (Verheijen et al. 2010, Cox et al. 2012, Hagemann et al. 2018, Tenic et al. 2020).
848 Most modern means of biochar production capture these byproducts, which are then either isolated or
849 burned to power the production process (Verheijen et al. 2010). However, if these byproducts were
850 released into the environment, it could result in the contamination of surrounding soil and water systems
851 and the atmosphere (Verheijen et al. 2010, Kusmierz and Oleszczuk 2014). Additionally, carbon dioxide is
852 produced as a component of syngas, and additional carbon dioxide is produced upon the combustion of
853 the syngas and bio-oil byproducts (Wang J et al. 2019). Crop residues are a common feedstock for biochar;
854 however, their removal for use as a feedstock may result in the loss of soil and nutrients and acceleration of
855 soil acidification (Lal and Pimentel 2007, Verheijen et al. 2010, Tenic et al. 2020). While the application of
856 biochar has been reported to improve the nutrient content of some soils, that result may be negated due to
857 nutrient loss when crop residues are harvested (Verheijen et al. 2010).

858

859 As described in the responses to Evaluation Questions 4 and 5, biochar production may also result in the
860 formation of PAHs, which have been classified as persistent carcinogens (Verheijen et al. 2010, Kusmierz
861 and Oleszczuk 2014, Grimmer 2018, Wang J et al. 2019). As described in the response to Evaluation
862 Question 5, certain feedstocks, particularly waste sludge and manure, may contain heavy metal
863 contaminants that would remain in the biochar (Veeken and Hamelers 2002, Park et al. 2011, Cox et al.
864 2012, Agrafioti et al. 2013). PAHs present within biochar remain bioavailable, and their desorption from the
865 substance can be enhanced by organic acids within the soil or chemicals excreted from plant roots (Jones
866 1998, Ling et al. 2015, Ren et al. 2018, Wang J et al. 2019). Therefore, if there are any PAHs present in
867 biochar, they may bioaccumulate within plant material—including food crops—of plants grown in biochar-
868 amended soils (Kahn et al. 2015, Wang et al. 2018, Wang J et al. 2019).

869

870 As described in the "Source or Origin of the Substance" section, organic residues (e.g., pesticides, manure
871 and sewage residues) have not been reported to carry over to the biochar product. This is likely due to the
872 biochar production conditions, which result in the thermal degradation of such substances.

873

874 Given the irreversible nature of biochar application, there is no immediate means of remediation for
875 biochar contaminated with PAHs or heavy metals once applied to the soil (Verheijen et al. 2010, Cox et al.
876 2012). PAH concentrations have been reduced over time due to microbial activity, and therefore PAH
877 contamination may pose a short-term threat, but it is unlikely to do long-term environmental harm (Wang J
878 et al. 2019). Heavy metal contaminants have been shown to have reduced bioavailability and soil mobility
879 in biochar compared to in their original feedstock source (Hwang et al. 2007, He et al. 2011, Agrafioti et al.

880   2013, Tenic et al. 2020). However, the incorporation of heavy metals from feedstocks combined with their
881   possible sequestration from contaminated soil may result in localized accumulations of pollutants
882   (Verheijen et al. 2010, Tenic et al. 2020).

884   **Evaluation Question #7: Describe any known chemical interactions between the petitioned substance**
885   **and other substances used in organic crop or livestock production or handling. Describe any**
886   **environmental or human health effects from these chemical interactions (7 U.S.C. § 6518(m)(1)).**

888   Biochar has been reported to have advantageous effects when combined with a range of fertilizers
889   (Lehmann et al. 2003, Yamato et al. 2006, Steiner et al. 2007, Verheijen et al. 2010, Zhang et al. 2010, Cox et
890   al. 2012). This is proposed to be due to the CEC properties of the substance, which supports the soil's
891   nutrients retention for plant uptake (Van Zwieten et al. 2010c, Cox et al. 2012, Bayabil et al. 2015, Lehmann
892   and Joseph 2015, Qian et al. 2015, Wang J et al. 2019, Tenic et al. 2020). A similar outcome could be expected
893   from a variety of other approved nutrient amendments, especially metal cations of salts. Potential salts that
894   may interact with biochar in the soil include calcium (Ca^{2+}) salts (calcium hypochlorite, lime sulfur,
895   hydrated lime); copper (Cu^{2+} and Cu^{3+}) salts (copper sulfate, copper hydroxide, copper oxide, copper
896   oxychloride); and magnesium (Mg^{2+}) salts (magnesium hydroxide and magnesium sulfate), as listed in 7
897   CFR 205.601.

899   These interactions result in nutrients being held in the soil, and they seem unlikely to pose a threat to
900   environmental or human health. Moreover, the addition of biochar to the soil will prevent the loss of these
901   soil nutrients and the contamination of nearby water systems by reducing nutrient run-off (Jiang et al. 2019,
902   Tenic et al. 2020). However, biochar has been reported to be long-lived in the environment (on the order of
903   hundreds to thousands of years); therefore, any subsequent addition of nutrients or fertilizers should be
904   carefully applied to prevent concentrations of metal nutrients that are too high or increased soil salinity.
905   Furthermore, the retention capacity of biochar increases over time due to oxidizing reactions within the
906   environment (Liang et al. 2006, Cheng et al. 2008, Cheng and Lehmann 2009, Verheijen et al. 2010, Cox et al.
907   2012).

909   As described in the "Action of the Substance" section, biochar may sequester various pesticides and
910   herbicides. Sequestration of these compounds prevents their uptake by crops and potential leaching into
911   water systems, which would have positive effects on environmental and human health. The ability of
912   biochar to sequester these compounds, and in some cases, to increase the rate of their environmental
913   degradation, may reduce their efficacy (Oni et al. 2019, Khalid et al. 2020). This may not be a desired effect
914   in some agricultural applications and may result in over application of the pesticide or herbicide in an
915   attempt to achieve the desired effect. Cases of over application may increase the risk of leaching into water
916   systems; therefore, over application of pesticides and herbicides due to reduced efficacy from biochar
917   sequestration may pose a risk to environmental and human heath (Oni et al. 2019, Khalid et al. 2020).

919   **Evaluation Question #8: Describe any effects of the petitioned substance on biological or chemical**
920   **interactions in the agro-ecosystem, including physiological effects on soil organisms (including the salt**
921   **index and solubility of the soil), crops, and livestock (7 U.S.C. § 6518(m)(5)).**

923   As discussed in the response to Evaluation Question 7, there are several possible effects of interactions
924   between biochar and the agro-ecosystem. The CEC properties of biochar are likely to enhance the retention
925   of soil nutrients and prevent their loss as run-off (Cox et al. 2012, Jiang et al. 2019, Tenic et al. 2020). As
926   discussed in the "Action of the Substance" section, biochar has been reported to have a liming effect,
927   particularly in acidic soils (Verheijen et al. 2010, Park et al. 2011, Cox et al. 2012, Spokas et al. 2012). The
928   increased pH resulting from biochar applications has been reported to improve the solubility and
929   bioavailability of nutrients, while reducing the bioavailability of toxic species, such as aluminum (Al)
930   (Tenic et al. 2020). Biochar has also been reported to reduce the mobility and bioavailability of heavy metals
931   in contaminated soils (Park et al. 2011, Agrafioti et al. 2013, Qian et al. 2015).

933   As discussed in the "Action of the Substance" section, biochar has been reported to improve soil
934   aggregation and may prevent soil loss due to erosion (Chan et al. 2003, Lehmann et al. 2011, Cox et al. 2012,

935 Blanco-Canqui 2017, Verheijen et al. 2019, Tenic et al. 2020). Biochar can affect the water retention of soils in
936 both a positive and negative manner. Studies suggest that water retention is influenced largely by the type
937 of soil rather than by the presence of biochar (Uzoma et al. 2011, Cox et al. 2012, Bayabil et al. 2015). When
938 biochar is applied, improvement in the water retention of soils is due to the porous nature of biochar and
939 the reduced density of biochar-amended soils (Asai et al. 2009, Verheijen et al. 2010, Uzoma et al. 2011, Cox
940 et al. 2012, de Jesus Duarte et al. 2019, Verheijen et al. 2019, Tenic et al. 2020).
941
942 Biochar has an impact on soil microorganism populations. Application of biochar can have a "priming"
943 effect caused by changes to both the carbon and nitrogen cycles of the soil and nutrient bioavailability
944 (Verhijen et al. 2010, Cross and Sohi 2011, Cox et al. 2012, Zimmerman et al. 2011, Tenic et al. 2020). The
945 priming effect on biochar-amended soil may be either positive or negative, although biochar application
946 generally results in long-term increases to microbial communities (Verheijen et al. 2010, Cox et al. 2012,
947 Tenic et al. 2020). These long-term increases have been reported to be due to the porous nature of biochar,
948 which provides microenvironments that foster the growth of microorganisms and protect them from
949 predation (Pietikainen et al. 2000, Warnock et al. 2007, Verheijen et al. 2010, Cox et al. 2012, Lehmann and
950 Joseph 2015). Several studies have been conducted on the effects of biochar on earthworm populations,
951 however, their results are inconsistent, including negative, neutral, and positive outcomes (Chan et al.
952 2008, Liesch et al. 2010, Van Zwieten et al. 2010b, Verheijen et al. 2010 Cox et al. 2012). These inconsistencies
953 are likely due to the great variation in biochar properties across feedstocks and production methods
954 coupled with the variation in environmental and soil conditions (Verheijen et al. 2010, Cox et al. 2012).
955
956 **Evaluation Question #9: Discuss and summarize findings on whether the use of the petitioned**
957 **substance may be harmful to the environment (7 U.S.C. § 6517(c)(1)(A)(i) and 7 U.S.C. § 6517(c)(2)(A)(i)).**
958
959 As discussed in Questions 5 and 6, biochar has several mechanisms that may result in negative
960 environmental impacts. Biochar production may result in the release of bio-oil and syngas byproducts,
961 which include carbon dioxide (Verheijen et al. 2010, Cox et al. 2012, Hagemann et al. 2018, Tenic et al.
962 2020).
963
964 Biochar production has been classified as carbon neutral or carbon negative (depending on production
965 conditions) since the carbon dioxide captured in the biomass during photosynthesis is sequestered as a
966 solid in biochar (Verheijen et al. 2010, Qian et al. 2015). All biomass, whether from animal or plant
967 feedstocks can eventually be traced back to plant sources. These are either directly plant-based, or animal
968 based whose nutrition is linked to plant consumption (Sohi et al. 2009, Verheijen at el. 2010). Plant growth
969 occurs through the process of photosynthesis through which CO_2 is captured from the atmosphere and
970 converted to sugars, biopolymers, and many other compounds (Sohi et al. 2009, Timberlake 2015).
971
972 The thermal degradation methods used for biochar production result in the transformation of much of the
973 carbon present in the biomass to highly stable forms such as graphene and aromatic molecules (Sohi et al.
974 2009, Verheijen et al. 2010, Lehmann and Joseph 2015). These compounds exhibit a dramatic increase in
975 their thermodynamic stability when compared to the unprocessed feedstock as well as alternative means of
976 processing (e.g., combustion, composting, etc.). This is linked to the stability in the resulting changes to
977 chemical structure when limited oxidation is possible (Silberberg 2003, Atkins et al. 2008, Timberlake 2016).
978 The enhanced stability of carbon within biochar results in its ability to sequester 50% of the carbon in the
979 biomass, compared to approximately 3% when the biomass is burned or composted (Nagula and
980 Ramanjaneyulu 2020). The potential for carbon sequestration is evidenced by the stability of biochar in soil
981 environments on the order of hundreds to thousands of years (Verheijen et al. 2010, Lehmann and Joseph
982 2015, Hagemann et al. 2018).
983
984 While CO_2 is released in the production of biochar, it is lower than the amount that was captured by the
985 biomass, resulting in a net carbon negative (Verheijen et al. 2010, Hertsgaard 2014, Kusmierz and
986 Oleszczuk 2014, Lehmann and Joseph 2015, Hagemann et al. 2018). Moreover, it is common practice for
987 some farmers to burn crop residues and introduce ashes into the soil as an amendment (Hertsgaard 2014).
988 The transition from burning residual crops to the pyrolysis of these materials has been linked to a
989 reduction in local air pollution and greenhouse gas production in the agricultural landscape of rural China,

990   while simultaneously resulting in a product that more effectively prevents the reemission of carbon into
991   the atmosphere (Hertsgaard 2014). Biochar represents an alternative for crop residues with a dramatic
992   reduction in CO_2 emissions compared to burning (combustion where CO_2 is a major product) due to the
993   anaerobic nature of biochar production (Silberberg 2003, Sohi et al. 2009, Timberlake 2015, Nagula and
994   Ramanjaneyulu 2020, Shalini et al. 2020).
995
996   Additionally, the ability of biochar to reduce the emissions of dangerous greenhouse gases such as
997   methane (CH_4) and nitrous oxide (N_2O), result in biochar production and usage a potential tool for climate
998   change (Singh et al. 2010, Verheijen et al. 2010, Zhang et al. 2010, Qian et al. 2015). While methane and
999   nitrous oxide are less prevalent than carbon dioxide in the atmosphere, they are more potent greenhouse
1000   gases and are more effective at trapping heat within the atmosphere than carbon dioxide (Singh et al. 2010,
1001   Verheijen et al. 2010, Zhang et al. 2010, Qian et al. 2015, Shalini et al. 2020). The stability of carbon in
1002   biochar, its ability to bind nitrogen sources, and its carbon to nitrogen ratio for composition result in
1003   changes to the carbon and nitrogen cycles within biochar amended soils (Singh et al. 2010, Verheijen et al.
1004   2010, Yao et al. 2010, Cox et al. 2012, Shalini et al. 2020). Studies show that biochar produced at high
1005   temperatures (>500 ℃) produces the most dramatic improvements of ammonia and ammonium soil
1006   retention due to its increased surface area (Asada et al. 2002, Clough and Condron 2012). There have also
1007   been reports of biochar's ability to bind nitrogen sources may improve over time through oxidation of the
1008   surface via weathering processes (Lehmann et al. 2003, Singh et al. 2010, Cox et al. 2012).
1009
1010   As discussed in Question 5, biochar may be contaminated with PAHs and heavy metals, depending on the
1011   feedstock and production conditions (Veeken and Hamelers 2002, Park et al. 2011, Cox et al. 2012, Fagernas
1012   et al. 2012, Agrafioti et al. 2013, Kusmierz and Oleszczuk 2014, Wang J et al. 2019). PAHs within biochar
1013   remain bioavailable and may accumulate in plants grown in biochar-amended soils (Kahn et al. 2015,
1014   Wang et al. 2018, Wang J et al. 2019). However, PAHs concentrations have been shown to be reduced over
1015   time due to the ability of microorganisms to metabolize the compounds (Rombola et al. 2015, Kusmierz et
1016   al. 2016, Wang J et al. 2019). Heavy metals in biochar have limited bioavailability but may result in
1017   localized accumulations of contaminants due to their lack of mobility (Verheijen et al. 2010, Tenic et al.
1018   2020).
1019
1020   **Evaluation Question #10: Describe and summarize any reported effects upon human health from use of**
1021   **the petitioned substance (7 U.S.C. § 6517(c)(1)(A)(i), 7 U.S.C. § 6517(c)(2)(A)(i)) and 7 U.S.C. § 6518(m)(4)).**
1022
1023   Human health effects from biochar result from the small particulate size (dust) of some products and its
1024   possible contamination with PAHs, which are addressed below.
1025
1026   *Dust*
1027
1028   Biochar can be produced as a fine dust, making it a potential respiratory health hazard and eye irritant
1029   (Cox et al. 2012, Biochar Industries 2013, Stormwater BIOCHAR 2018, Aries GREEN 2019). These dust
1030   hazards are applicable during production, transport, and application (Cox et al. 2012). When handling
1031   biochar dust, appropriate personal protective equipment should be used and the biochar should be
1032   watered to dampness to prevent it from becoming airborne (Cox et al. 2012, Biochar Industries 2013,
1033   Stormwater BIOCHAR 2018, Aries GREEN 2019).
1034
1035   *Polycyclic aromatic hydrocarbons (PAH)*
1036
1037   As discussed in the response to Evaluation Question 5, biochar production conditions also result in the
1038   formation of polycyclic aromatic hydrocarbons (PAH), some of which have been classified as persistent
1039   carcinogens (Verheijen et al. 2010, Kusmierz and Oleszczuk 2014, Grimmer 2018, Wang J et al. 2019).
1040   Studies have shown that biochars with elevated PAH concentrations may pose a health risk to humans that
1041   come into contact with the biochars, amended soils, and food products harvested from the amended soils
1042   (Oleszczuk et al. 2013, Kusmierz and Oleszczuk 2014, Wang J et al. 2019). Additionally, the easily airborne
1043   dust particles may pose a significant threat to biochar production workers if they lack proper personal
1044   protective equipment (Cox et al. 2012, Kusmierz and Oleszczuk 2014).

1045
1046   As discussed in the responses to Evaluation Questions 4 and 5, microorganisms in biochar-amended soils
1047   decompose PAHs, which suggests that PAH contamination of soils will decrease over time (Rombola et al.
1048   2015, Kusmierz et al. 2016, Wang J et al. 2019). PAH concentrations may also be decreased through aging or
1049   drying processes, which have been reported to greatly reduce or eliminate PAH content from the aged and
1050   dried biochar (Koltowski and Oleszczuk 2015, Oleszczuk and Koltowski 2018, Wang J et al. 2019).
1051
1052   Studies of biochar-amended soils show that airborne PAH exposure from the soils poses little-to-no risk to
1053   humans (Wang J et al. 2019). Moreover, PAHs from contaminated soils have been shown to pose negligible
1054   risk to nearby water supplies, likely due to the sorbent quality of the biochar, which keeps PAHs from
1055   leaching out of the soil (Hale et al. 2012, Wang J et al. 2019).
1056
1057   As discussed in the response to Evaluation Question 5, PAHs have been reported to bioaccumulate in food
1058   crops that were grown in biochar-amended soils (Kahn et al. 2015, Wang et al. 2018, Wang J et al. 2019).
1059   PAH concentration in food crops varies based on crop type, although accumulation has been reported in
1060   wheat, rice, leafy vegetables, and root vegetables (Wang J et al. 2019). The concentration of PAH
1061   accumulation in food crops has resulted in some portion of several crops (up to 14% of those in the study)
1062   being classified as "low risk," according to guidelines set forth by the United States Environmental
1063   Protection Agency (EPA) and poses the greatest biochar risk to the general population (Wang J et al. 2019).
1064
1065   While biochar does contribute to PAH contamination of soils and crops, its contribution is minimal in
1066   comparison to PAH contamination from microbial synthesis, forest fires, volcanic activity, and combustion
1067   of fossil fuels (Song et al. 2006, Nam et al. 2008, Wang J et al. 2019). Given the relatively low human health
1068   risks of biochar at low application rates and the potential to lower PAH content through post-production
1069   treatments, Wang et al. have declared biochar soil amendment to be low risk by EPA standards (Wang J et
1070   al. 2019).
1071
1072   **Evaluation Question #11: Describe all natural (non-synthetic) substances or products which may be**
1073   **used in place of a petitioned substance (7 U.S.C. § 6517(c)(1)(A)(ii)). Provide a list of allowed substances**
1074   **that may be used in place of the petitioned substance (7 U.S.C. § 6518(m)(6)).**
1075
1076   There are a range of natural and approved substances that may be used in place of biochar for some of its
1077   agricultural applications. These substances will be discussed based on how their potential applications
1078   compare to those of biochar.
1079
1080   *Soil amendment*
1081
1082   There are many natural soil amendments that may be used in place of biochar. Alternative nutrient sources
1083   include the raw versions of several biochar feedstocks, such as amino acids, animal byproducts, crop
1084   remnants, wood products, compost, manures, and mulch (NOP 2016a). These substances are all-natural
1085   nutrient sources, and the nutrients they contain are more bioavailable than those found in biochar.
1086   Approved synthetic substances with nutrients present include inorganic salts such as copper sulfate,
1087   elemental sulfur, lime sulfur, hydrated lime, ferric phosphate, potassium bicarbonate, and micronutrients,
1088   as listed in 7 CFR 205.601.
1089
1090   Due to the increase bioavailability of nutrients in these substances, they will also be more prone to run-off
1091   and potential pollution of neighboring water systems when compared to biochar (Jiang et al. 2019, Tenic et
1092   al. 2020). The above alternative would also require a greater frequency of application compared to biochar
1093   (Cox et al. 2012, Tenic et al. 2020). While nutrients in these alternatives are more bioavailable than in
1094   biochar, the bioavailability of heavy metals in biochar is lower than in raw manures due to pyrolysis
1095   conditions (Tenic et al. 2020).
1096
1097   Activated charcoal and some clays have all been reported to have CEC properties and may provide
1098   alternatives to biochar in their ability to retain nutrients (USDA 2002, Kammerer et al. 2011, Marakatti et al.
1099   2014, Hagemann et al. 2018). As discussed in "Activated Charcoal vs Biochar," the two substances share

1100   many similarities, including feedstocks, chemical properties, structure and composition, and some
1101   production conditions (Renner 2007, Cox et al. 2012, Anderson et al. 2013, Verheijen et al. 2010, Hagemann
1102   et al. 2018, Wang J et al. 2019, Tenic et al. 2020). Some clays contain natural zeolites, which have been
1103   reported to have cation or anion exchange capacities (Kammerer et al. 2011, Marakatti et al. 2014, USDA
1104   2020). Chelating agents also provide an alternative method to retain soil nutrients while maintaining
1105   bioavailability (USDA 2018a, USDA 2018b). Lignin sulfonate is an approved alternative chelating agent
1106   (USDA 2018a, USDA 2018b).
1107
1108   Mulches, composts, ash, clay, crop residues, peat, and manures are potential alternatives to biochar to
1109   improve soil aggregation and water retention. However, they have a relatively short lifetime in soil
1110   compared to biochar and would require more frequent application (Cox et al. 2012).
1111
1112   There are several alternatives to biochar to increase soil pH, including sodium carbonate, potassium
1113   bicarbonate, calcium acetate, calcium carbonate mineral sources, calcium hydroxide, and lime sulfur (NOP
1114   2016a).
1115
1116   *Soil remediation (decontamination of heavy metals)*
1117
1118   The effectiveness of biochar for heavy metal decontamination applications is due to the CEC properties of
1119   the substance (Silberberg 2003, Park et al. 2011, Agrafioti et al. 2013, Qian et al. 2015). Therefore, the same
1120   alternatives to the soil nutrient retention applications of biochar are candidates for the sequestration of
1121   heavy metal contaminants (lignin sulfonate). While clays and chelators offer the ability to reduce the
1122   bioavailability of heavy metals, they may be prone to degradation within the soil system, which would
1123   release the sequestered contaminants back into the soil (USDA 2018a, USDA 2018b).
1124
1125   Plants can also be grown to uptake heavy metals from soils through a process known as phytoremediation.
1126   Several studies have reported heavy metal uptake by plants in soils even when grown in the presence of
1127   soils with high CEC properties (Lambert et al., Veeken and Hamelers 2002, Park et al. 2011, Cox et al. 2012,
1128   Agrafioti et al. 2013). The viability of plants for heavy metal soil remediation is dependent on the level of
1129   contamination and type of plant, and plant-based remediation is typically the slowest means of heavy-
1130   metal soil remediation (Lambert et al.)
1131
1132   **Evaluation Question #12: Describe any alternative practices that would make the use of the petitioned**
1133   **substance unnecessary (7 U.S.C. § 6518(m)(6)).**
1134
1135   Alternative practices that may make the use of biochar unnecessary include the application of a compost
1136   program and the application of manure. Compost and manure are natural sources of nutrients and contain
1137   chelating agents and microbes that produce natural compounds that help retain bioavailable soil nutrients
1138   (Chen et al. 1998, Sorrenti et al. 2012, Adeleke et al. 2017).
1139
1140   Direct application of residual crops provides another alternative practice to biochar application. The direct
1141   application of crop remnants to agricultural soils has been reported to increase organic matter within soils
1142   and to improve water retention (Jones et al. 2005, Ji et al. 2019). Additionally, the reapplication of residual
1143   crops to fields rather than use as biochar feedstock prevents the loss of soil and existing nutrients and the
1144   acceleration of soil acidification following the removal process (Lal and Pimentel 2007, Verheijen et el. 2010,
1145   Tenic at el. 2020).
1146

1147   **Report Authorship**

1148
1149   The following individuals were involved in research, data collection, writing, editing, and/or final
1150   approval of this report:
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1152   • Philip Shivokevich, Visiting Assistant Professor of Chemistry, University of Massachusetts
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1155
1156 All individuals are in compliance with Federal Acquisition Regulations (FAR) Subpart 3.11—Preventing
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1158

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