Activated Charcoal

Livestock

Identification of Petitioned Substance

Chemical Name:
Carbon

Other Names:
Charcoal
Medicinal charcoal
Activated carbon
Medicinal carbon

Trade Names:
N/A

CAS Numbers:
Carbon: 7440-44-0

Other Codes:
EINECS No. 231-153-3

Summary of Petitioned Use

The United States Department of Agriculture (USDA) National Organic Program (NOP) has approved the use of activated charcoal as a "synthetic substance allowed for use in organic livestock production," with the stipulation that it "must be from vegetative sources" in 7 CFR 205.603. Furthermore, the NOP has clarified that the allowed use of activated charcoal is "as a therapeutic treatment on an as-needed basis with mammalian livestock in cases of suspected ingestion of toxic plants and control of diarrhea caused by moldy silage" (NOP 2018). The NOP has also approved the use of activated charcoal as a synthetic substance "allowed as an ingredient in or on processed products labeled as 'organic' or 'made with organic'" with the stipulation that it "must be from vegetative sources; for use only as a filtering aid" in 7 CFR 205.605.

This report was requested by the National Organic Standards Board (NOSB) to update the previous information on activated charcoal in support of the upcoming sunset review for the substance (USDA 2002a). This report will focus on the veterinary applications of activated charcoal to organic livestock production.

Characterization of Petitioned Substance

Composition of the Substance:
Elemental carbon makes up the majority of activated charcoal, with its surface area being enhanced in the activation process (EFSA 2011, SA 2020). Activated charcoal is not uniform in production and composition (Verheijen et al. 2010, Cox et al. 2012, Hagemann et al. 2018, Kalus et al. 2019). There are many possible feedstocks and production conditions for manufacturing activated charcoal (Anatal and Gronli 2003, Verheijen et al. 2010, Cox et al. 2012, Kalus et al. 2019).

Activated charcoal may also include various aromatic compounds that are formed during the production process (Sohi et al. 2009, Verheijen et al. 2010, Timberlake 2016). The identity and prevalence of these compounds within activated charcoal are dependent on feedstock and production conditions. These compounds are primarily composed of carbon and hydrogen atoms but may also include oxygen, nitrogen, and sulfur incorporated within the molecular structure (Anatal and Gronli 2003, Sohi et al. 2009, Verheijen et al. 2010).

Source or Origin of the Substance:
Activated charcoal is produced by the thermochemical degradation of biomass in the absence of oxygen followed by chemical or physical activation (Flomenbaum et al. 2002, Verheijen et al. 2010, EFSA 2011, Cox et al. 2012, Hagemann et al. 2018, Kalus et al. 2019). Activated charcoal can be produced from a range of feedstocks from both plant and animal sources, although activated charcoal allowed for organic production

is limited to vegetative sources, as described in 7 CFR 205.603. Typical vegetative sources include nut shells, sugarcane bagasse, coconut husks, cotton, crop remnants, grain remnants, grass residues, wood chips, and tree bark (Flomenbaum et al. 2002, Sohi et al. 2009, Verheijen et al. 2010, Park et al. 2011, Cox et al. 2012, Agrafioti et al. 2013, Bayabil et al. 2015, Kalus et al. 2019). Typical animal sources include manures (cattle and poultry), bone as bone char or bone black, meat, blood, and sewage sludge from human sources (USDA 2002a, Kalus et al. 2019, Lao and Mbega 2020). Additionally, charcoal can be produced from coal sources (Anderson et al. 2013, Hagemann et al. 2018).

Properties of the Substance:
Activated charcoal is a black solid and is generally sold in powder form. However, activated charcoal for medicinal purposes may also be sold as pellets or biscuits or as a slurry when mixed with water (Flomenbaum et al. 2002, EFSA 2011). The general properties of activated charcoal are listed in Table 1.

Table 1. Properties of activated charcoal

Appearance	Black powder or pellets
CAS No. (Carbon)	7440-44-0
Molecular weight	12.01 g/mol
Water solubility	Not soluble
Melting point	3,550 °C (6,442 °F)
Vapor pressure	1 hPa at 25 °C (77 °F)
Odor	Odorless
Relative density	1.8–2.1 g/cm^3

Sources: Flomenbaum et al. 2002, PC 2017, SA 2020

Activation of charcoal results in a dramatic increase in surface area, including the creation of many micropores, contributing to surface areas that range from 800 to 3,500 m^2/g (Olsen 2010, EFSA 2011, Lao and Mbega 2020). Charcoal has been noted to have high sorbent capacity, which is enhanced in activated charcoal due to increased surface area (Olsen 2010, EFSA 2011, Lao and Mbega 2020). Activated charcoal has high adsorption character for neutral molecules and large ions whose primary intermolecular forces are Van der Waals interactions (Flomenbaum et al. 2002, Silberberg 2003, Olsen 2010).

Specific Uses of the Substance:
The high sorbent value of activated charcoal makes it useful for applications in processing—including decolorizing processes and water and food product purification—and as a medical treatment for humans and animals (Poage et al. 2000, Lapus 2007, Snyman et al. 2009, Olsen 2010, Mgbeahuruike et al. 2018, Kalus et al. 2019).

In livestock production, activated charcoal has applications as an ingredient in animal feeds and as a veterinary treatment (Poage et al. 2000, Mgbeahuruike et al. 2018, Kalus et al. 2019, Lao and Mbega 2020). However, current NOP guidelines allow the use of activated charcoal for veterinary purposes only (NOP 2018). Activated charcoal is used as a veterinary treatment for livestock that have ingested various toxic substances, including phytotoxins and mycotoxins, to prevent the animal's absorption of the substance (Poage et al. 2000, Flomenbaum et al. 2002, Snyman et al. 2009, Mgbeahuruike et al. 2018).

Activated charcoal is used in conventional livestock feeds to remove potential toxic components that may have been introduced into the feed during processing and/or storage; activated charcoal in livestock feeds serves as a preventative measure against possible consumption of toxic compounds within the agro-ecosystem (Oluwafemi et al. 2014, Mgbeahuruike et al. 2018, Kalus et al. 2019, Lao and Mbega 2020). The addition of activated charcoal to animal feeds has also been reported to increase animal weight gain, remove toxins from milk, and improve the quality of milk and poultry eggs (Oluwafemi et al. 2014, Mgbeahuruike et al. 2018, Kalus et al. 2019, Lao and Mbega 2020).

Approved Legal Uses of the Substance:
The NOP has approved activated charcoal as a "synthetic substance allowed for use in organic livestock production" with the stipulation that it is produced "from vegetative sources" in 7 CFR 205.603. The NOP has

also approved the use of activated charcoal "from vegetative sources as a filtering aid" in "processed products labeled as 'organic' or 'made with organic'" in 7 CFR 205.605.

The United States Food and Drug Administration (FDA) lists activated charcoal as a treatment method for aspirin overdose in 21 CFR 343.80. The FDA includes the following specific treatment guidelines following aspirin overdose: "after lavage and/or emesis, administration of activated charcoal, as a slurry, is beneficial, if less than 3 hours have passed since ingestion."

The FDA allows the use of activated charcoal as an active ingredient in over-the-counter medicines used as diarrheal treatments and the use of both activated and wood charcoal in digestive aids in 21 CFR 310.545. The FDA allows the use of charcoal for the purification steps of the production of synthetic paraffin in 21 CFR 172.250 and 172.615.

Action of the Substance:

Activated charcoal has a large surface area with a high sorption capacity (EFSA 2011). The medicinal/veterinary applications of activated charcoal are based on this high sorption capacity, which is utilized to remove xenobiotic toxins before they are absorbed by the animal through interruptions to the enterohepatic and enteroenteric cycles (Poage et al. 2000, Flomenbaum et al. 2002, Lapus 2007, Snyman et al. 2009, Mgbeahuruike et al. 2018, Zellner et al. 2019). One study claims that the capacity of activated charcoal to be used as a general adsorbent "makes it the single most useful agent in the management of a broad variety of patients with acute oral overdoses" (Flomenbaum et al. 2002). There is no dosage standard, as activated charcoal adsorption varies based on the toxin, but a 10:1 ratio of activated charcoal to toxin is generally accepted (Flomenbaum et al. 2002, Olsen 2010). When the amount of toxin is unknown, the recommended dosage is 1g/kg (Flomenbaum et al. 2002). Additionally, the presence of activated charcoal in the gastrointestinal tract, when applied in multiple doses, may remove toxins already in the bloodstream via passive diffusion processes (Flomenbaum et al. 2002, Lapus 2007).

As described in the "Composition of the Substance" and "Properties of the Substance" sections above, activated charcoal is primarily made up of elemental carbon that lacks functional groups, making Van der Waals interactions its primary means of adsorbing compounds. This makes activated charcoal an effective adsorption treatment for large neutral molecules and large ions whose primary intermolecular forces are also Van der Waals interactions (Flomenbaum et al. 2002, Olsen 2010). However, activated charcoal is a relatively ineffective treatment for small molecules and highly charged ions due to their limited Van der Waals interactions (Flomenbaum et al. 2002, Lapus 2007, Olsen 2010, Zellner et al. 2019). Table 2 lists common toxins that are both effectively and ineffectively treated by activated charcoal.

Table 2. Common toxins and effectiveness of activated charcoal treatments

Activated charcoal is effective for treatment of:		**Activated charcoal is ineffective for treatment of:**
Drugs/toxins	*Phytotoxins*	
ACE inhibitors	amatoxin (death cap)	hydrocarbons
amphetamines	aconitine (aconite)	acids
antidepressants (except lithium)	colchicine (autumn crocus)	alkalis
antiepileptics	cucurbitacin (courgette, Cucurbitaceae)	cyanides
antihistamines		inorganic salts (e.g., sodium chloride)
aspirin/salicylates	ergotamine/ergot alkaloids	
atropine	ibotenic acid/muscarine (fly agaric, panther cap)	heavy metals (e.g., iron, lead)
barbiturates		ethanol
benzodiazepines	nicotine (tobacco)	organic solvents (e.g., acetone, dimethyl sulfoxide)
beta blockers	ricin (castor oil plant)	
calcium-channel blockers	strychnine (nux vomica)	
quinine/quinidine	taxanes (yew)	
chloroquine/primaquine	digitalis glycosides (foxglove)	
dapsone	yellow tulp	
digoxin/digitoxin	butterweed	
diuretics (e.g., furosemide, torasemide)		
nonsteroidal antirheumatics (NASR)		
neuroleptics		
oral antidiabetics (e.g., glibenclamide, glipizide)		
opiates/dextromethorphan		
paracetamol		
piroxicam		
tetracyclines		
theophylline		
mercuric chloride ($HgCl_2$)		

Sources: Poage et al. 2000, Flomenbaum et al. 2002, Lapus 2007, Snyman et al. 2009, Olsen 2010, Zellner et al. 2019

Activated charcoal and charcoal additives in animal feeds have been reported to increase feed intake, promote weight gain, and improve the quality of animal products such as eggs, milk, and meat (Kutlu et al. 2001, Toth and Dou 2016, Mgbeahuruike et al. 2018, Kalus et al. 2019, Lao and Mbega 2020). The addition of charcoal or activated charcoal to animal feeds adsorbs toxins that may have been ingested by the livestock within the agro-ecosystem (e.g., tallow oleander, yew, bitterweed) or present in animal feeds due to improper collection or storage. The addition of activated charcoal to animal feeds is reported to offer protection from potential toxins within the feed as well as naturally occurring toxins in plants that may be ingested through grazing (Poage et al. 2000, Oluwafemi et al. 2014, IARC 2015, Mgbeahuruike et al. 2018, Kalus et al. 2019, Lao and Mbega 2020). The application of activated charcoal for improving milk quality is the same as the veterinary applications described above.

The quality of animal products, such as eggs, milk, and meat, is improved by preventing potential toxins from being absorbed by the animal and passing into these products (Oluwafemi et al. 2014, Mgbeahuruike et al. 2018, Kalus et al. 2019, Lao and Mbega 2020). Incorporation of charcoal and activated charcoal into animal feeds has been reported to increase quantity of eggs and egg quality with reductions in the number of cracked eggs (Kutlu et al. 2001, Kalus et al. 2019, Lao and Mbega 2020). The incorporation of activated charcoal (1%) into animal feeds has also been reported to reduce mycotoxins in milk by up to 76% (Rao et al. 2004, Kalus et al. 2019, Lao and Mbega 2020). There have also been reports of the incorporation of activated charcoal into animal feeds providing protection from harmful microbes, possibly by providing environmental niches that promote the growth of beneficial bacterial communities (Knutson et al. 2006, Calloway et al. 2012). However, there are several conflicting reports on the effect of activated charcoal on gut bacteria and further study is needed (Lao and Mbega 2020).

Combinations of the Substance:

Activated charcoal is commonly administered as a water slurry in veterinary applications with eight parts water to one part activated charcoal (Flomenbaum et al. 2002, EFSA 2011). The water slurry helps to administer the activated charcoal and prevents emesis. When activated charcoal is used as a feed ingredient, it is added to the animal feed for direct ingestion.

Activated charcoal is also often administered as a slurry in human medical applications as a treatment for ingestion of various toxic substances (Flomenbaum et al. 2002). When used for human application, activated charcoal can be administered as a slurry with many food and beverage products—including yogurt, ice cream, chocolate syrup, cherry syrup, sorbitol, saccharin, melted milk chocolate, milk, soda, juice, and orange or peppermint oils—in an attempt to make the activated charcoal more palatable (Flomenbaum et al. 2002). The administration of activated charcoal with food or flavored beverage products is most common when treating children, although clinical guidelines state that administration as a water slurry is most effective (Flomenbaum et al. 2002).

When used as an animal feed additive (for conventional agricultural production), activated charcoal is added directly to animal feeds at approximately 1–3% (Kalus et al. 2019, Lao and Mbega 2020).

Status

Historical Use:

Charcoal has a long-established history of use in medical practices, dating back to 1500 BCE (Maketos and Androutsos 2004, Lapus 2007, Olsen 2010). The ancient Egyptians used charcoal to adsorb toxins from wounds, while ancient Greeks used it as a treatment for epilepsy, chlorosis, and anthrax (Marketos and Androutsos 2004, Lapus 2007). Charcoal began to gain recognition as an adsorbent species capable of treating liquids and gases in the 1700s, leading up to its dramatic demonstration as a poison treatment in 1831 when a pharmacist survived the ingestion of strychnine in greater than the lethal dose with equal parts charcoal (Marketos and Androutsos 2004, Lapus 2007).

Activated charcoal was first produced in Austria in 1911, and it gained widespread use as the primary adsorbent in gas masks during World War I (Lapus 2007). Activated charcoal has been administered as an adsorbent for toxic substances for 200 years, gaining use as a broad-spectrum treatment in the 1940s (Flomenbaum et al. 2002). Administration of activated charcoal as a treatment for the ingestion of toxins became widely accepted in the 1960s following the publication of a prominent review article in the Journal of Pediatrics (Derlet and Albertson 1986, Lapus 2007).

Organic Foods Production Act, USDA Final Rule:

Activated charcoal is not listed in the Organic Foods Production Act of 1990 (OFPA). Activated charcoal is, however, listed in 7 CFR 205.603 as a "synthetic substance allowed for use in organic livestock production" with the stipulation that it is produced "from vegetative sources." Activated charcoal also appears "from vegetative sources as a filtering aid" in "nonagricultural (nonorganic) substances allowed as ingredients in or on processed products labeled as 'organic' or 'made with organic'" in § 205.605.

International

Canadian General Standards Board Permitted Substances List

Activated charcoal is listed in the Canadian General Standards Board Permitted Substances List in "Table 5.3 – Health care products and production aids" with the stipulation that the charcoal "shall be of plant origin." Activated charcoal is also listed in "Table 6.3 – Ingredients classified as food additives" and "Table

6.5 – Processing aids," with the stipulation that the charcoal "shall be of plant origin" and that its use is "prohibited in the production of maple syrup."

CODEX Alimentarius Commission, Guidelines for the Production, Processing, Labelling and Marketing of Organically Produced Foods (GL 32-1999)

Activated charcoal is not listed in the CODEX; however, "wood ash and wood charcoal" are listed in "Table 1: Substances for use in soil fertilizing and conditioning," with the stipulation that the charcoal must be produced "from wood not chemically treated after felling."

European Economic Community (EEC) Council Regulation, EC No. 834/2007 and 889/2008

Activated charcoal is not listed in the EEC EC No. 834/2007 or 889/2008.

Japan Agricultural Standard (JAS) for Organic Production

Activated charcoal is not listed in the JAS; however, charcoal is listed in "Attached Table 1 – Fertilizers and soil improvement substances" in JAS notifications No. 1605 and No. 1608 with the limitation that the charcoal must be "derived from natural sources, or natural sources without the use of chemical treatment."

International Federation of Organic Agriculture Movements (IFOAM)

Activated charcoal is not listed in the IFOAM NORMS for organic production and processing; however, "wood charcoal" is listed in "Appendix 2: Fertilizers and soil conditioners" as allowed "if not chemically treated."

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

__Evaluation Question #1: Indicate which category in OFPA that the substance falls under:__ **(A) Does the substance contain an active ingredient in any of the following categories: copper and sulfur compounds, toxins derived from bacteria; pheromones, soaps, horticultural oils, fish emulsions, treated seed, vitamins and minerals; livestock parasiticides and medicines and production aids including netting, tree wraps and seals, insect traps, sticky barriers, row covers, and equipment cleansers? (B) Is the substance a synthetic inert ingredient that is not classified by the EPA as inerts of toxicological concern (i.e., EPA List 4 inerts) (7 U.S.C. § 6517[c][1][B][ii])? Is the synthetic substance an inert ingredient which is not on EPA List 4, but is exempt from a requirement of a tolerance, per 40 CFR part 180?**

Activated charcoal does not contain any active ingredients listed in part (A) of this question. Activated charcoal's makeup is varied due to the range of feedstocks and processing conditions used in commercial sources (Anatal and Gronli 2003, Verheijen et al. 2010, Kalus et al. 2019).

In response to part (B). of this question, activated charcoal that "meets specifications in the Food Chemical Codex" is listed by the Environmental Protection Agency (EPA) as an "inert ingredient used in pre- and post-harvest" with "exemptions from the requirement of a tolerance" in 40 CFR 180.910.

__Evaluation Question #2:__ **Describe the most prevalent processes used to manufacture or formulate the petitioned substance. Further, describe any chemical change that may occur during manufacture or formulation of the petitioned substance when this substance is extracted from naturally occurring plant, animal, or mineral sources (7 U.S.C. § 6502[21]).**

Charcoal can be activated through physical or chemical means, during the production process or as a second step, that increase the surface area and change the surface chemistry of the activated charcoal product (EFSA 2011, Hagemann et al. 2018, Lao and Mbega 2020). Charcoal is produced by the thermal degradation of biomass (e.g., wood chips, grasses, crop remnants) in the absence of oxygen or in a limited oxygen environment (Flomenbaum et al. 2002, USDA 2002a, EFSA 2011, Cox et al. 2012, Anderson et al.

2013, Verheijen et al. 2010, Hagemann et al. 2018, Kalus et al. 2019, Wang J et al. 2019). There are several methods to produce charcoal, with the most common production methods being torrefaction, pyrolysis, and gasification (Verheijen et al. 2010, Cox et al. 2012, Kalus et al. 2019).

Charcoal production

All three charcoal production processes (i.e., torrefaction, pyrolysis, and gasification) result in the formation of multiple products: solid products (which are further activated to produce activated charcoal), bio-oil (liquids), and syngas (gases) (Verheijen et al. 2010, Cox et al. 2012, Hagemann et al. 2018, Kalus et al. 2019, Lao and Mbega 2020). The ratio of products varies depending on production method and feedstock properties (Hagemann et al. 2018, Kalus et al. 2019, Lao and Mbega 2020).

Pyrolysis is the most common production process and has been optimized for maximum charcoal yield (Verheijen et al. 2010, Cox et al. 2012, Hagemann et al. 2018, Kalus et al. 2019). Pyrolysis is the traditional method of charcoal production, and modern methods of pyrolysis produce the greatest yield of activated charcoal compared to liquid and syngas. It is also the most common method for producing activated charcoal (Verhijen et al. 2010, Cox et al. 2012, Lao and Mbega 2020). The pyrolysis conditions used to produce activated charcoal require temperatures that range from 450 ˚C to 900 ˚C to be applied for relatively short amounts of time (<30 seconds) (Cox et al. 2012, Hagemann et al. 2018, Kalus et al. 2019, Lao and Mbega 2020). In order to facilitate charcoal production during these short heating time periods, the biomass must be reduced to small particles with a moisture content of less than 10% (Verheijen et al. 2010, Cox et al. 2012). The charcoal that is produced through pyrolysis tends to have increased porosity and surface area because pyrolysis requires a higher temperature and pressure compared to other production methods; this is favorable for activated charcoal production (Cox et al. 2012).

Activation

Once charcoal has been produced, it undergoes an activation process that increases its sorption abilities by dramatically increasing the surface area of the carbon substrate (Flomenbaum et al. 2002, USDA 2002a, EFSA 2011, Hagemann et al. 2018, Lao and Mbega 2020). The charcoal may be activated via chemical or physical means (USDA 2002a, Hagemann et al. 2018).

Chemical activation requires an activation agent, such as zinc(I) chloride ($ZnCl$), iron(III) chloride ($FeCl_3$), sulfuric acid (H_2SO_4), phosphoric acid (H_3PO_4), hydrochloric acid (HCl), nitric acid (HNO_3), sodium or potassium hydroxide ($NaOH/KOH$), or sodium or potassium carbonate ($NaCO_3/KCO_3$) (USDA 2002a, Marsh and Reinoso 2006, Hagemann et al. 2018, Lao and Mbega 2020). Chemical activation processes also include washes of the activated product to remove the activating agents; chemical activation agents are commonly collected and reused (Hagemann et al. 2018).

In chemical activation processes, the biomass is mixed with and heated in the presence of the chemical activator to promote chemical oxidation processes. The activation process results in chemical and physical changes to the charcoal surface, which is characterized by the removal of organic functional groups and an increase in surface area that is primarily due to the creation of pores (Hagemann et al. 2018, Laog and Mbega 2020). The degree of activation is based on the chemical activator, the feedstock, and the temperatures used in the activation process. Generally, activation increases with higher concentrations of the chemical oxidant, higher temperatures, and repetition of the activation processes (Hagemann et al. 2018, Lao and Mbega 2020). However, extended activation residence times and temperatures may reduce the surface area of the activated charcoal by weakening its structural character, resulting in the collapse of micropores (Hagemann et al. 2018).

Alternatively, activated charcoal can be produced in a way that combines thermal decomposition and activation into a single step (Marsh and Reinoso 2006, Hagemann et al. 2018). Chemical activation is often used in the single-step conversion of biomass to activated charcoal. In single-step applications, the chemical oxidant is added prior to the pyrolysis process, and activation occurs in the initial heating step (Hagemann et al. 2018). Single-step production of charcoal with chemical activation becomes effective as the oxidant begins to degrade large biomolecules (e.g., cellulose, lignin, starches) through chemical oxidation, which increases the surface area of the charcoal and the efficiency of the thermochemical degradation processes (Hagemann et al. 2018, Lao and Mbega 2020). Chemical activation is more common than physical activation because of its ability to be incorporated into single-step production and lower temperature requirement (Hagemann et al. 2018).

Physical activation of charcoal uses gases to increase surface area, including air, steam (H_2O), nitrogen (N_2), and carbon dioxide (CO_2) (Flomenbaum et al. 2002, USDA 2002a, Marsh and Reinoso 2006, Hagemann et al. 2018). Like chemical activation processes, physical activation must occur at a high temperature to facilitate oxidation processes. These processes result in physical and chemical changes to the surface of the charcoal that are similar to those cause by chemical activation (Olson 2010, Hagemann et al. 2018, Lao and Mbega 2020). Due to the mild reactivity of the gases used in physical activation compared to the oxidants used in chemical activation, physical activation processes generally require higher temperatures (Hagemann et al. 2018).

Evaluation Question #3: Discuss whether the petitioned substance is formulated or manufactured by a chemical process or created by naturally occurring biological processes (7 U.S.C. § 6502(21)).

The NOP has classified the "heating or burning" of biological matter as a natural process, and therefore, substances that are produced via heating or burning processes are considered non-synthetic (NOP 2016a, NOP 2016b). An example of this classification is "ash from manure burning," which is classified as a natural substance that is prohibited for use in agricultural production, as described in 7 CFR 205.602. Under these guidelines, charcoal, which is produced by heating biological matter, is considered a natural, non-synthetic substance (NOP 2016a, NOP 2016b). Additionally, charcoal can be found in nature as a product of forest fires (Verheijen et al. 2010, Wang J et al. 2019).

Activated charcoal differs from charcoal precursors because of changes that occur during the activation process. As described in Evaluation Question 2, the activation of charcoal may occur by chemical or physical activation processes, both of which result in chemical and physical changes to the charcoal precursor. These chemical and physical changes are due to oxidation processes that occur by combining high temperatures and high gas pressures (physical activation) or applying chemical oxidants (chemical activation). While these activation processes occur by heating biological matter, the chemical and physical changes that occur due to the activation process are not caused by increased temperatures alone. The oxidizing conditions for chemical *and* physical charcoal activation are not considered to be natural processes; because of this, activated charcoal is classified of as a synthetic substance according to the NOP decision tree in 5033-1 (NOP 2016b).

Evaluation Question #4: Describe the persistence or concentration of the petitioned substance and/or its by-products in the environment (7 U.S.C. § 6518(m)(2)).

As discussed previously in the section "Composition of the Substance," activated charcoal is primarily composed of elemental carbon with various numbers of aromatic molecules (Sohi et al. 2009, Verheijen et al. 2010). These compounds are highly thermodynamically stable, making them resistant to chemical and biological decomposition (Cox et al. 2012). Due to the stability of its bulk components, charcoal is long-lived in the environment, having persistence on the order of hundreds to thousands of years (Cox et al. 2012).

Evaluation Question #5: Describe the toxicity and mode of action of the substance and of its breakdown products and any contaminants. Describe the persistence and areas of concentration in the environment of the substance and its breakdown products (7 U.S.C. § 6518(m)(2)).

Activated charcoal may contain toxic substances, depending on feedstock and production conditions. These substances include heavy metals, which are not degraded by thermal decomposition processes and can be carried over into the activated charcoal product if they were present in the biomass used as feedstock (Park et al. 2011, Wang J et al. 2019). Heavy metals are most prevalent in wastes, such as sewage sludge and manures. (Veeken and Hamelers 2002, Park et al. 2011, Cox et al. 2012, Agrafioti et al. 2013, Kalus et al. 2019). These feedstocks have been reported to contain chromium (Cr), lead (Pb), copper (Cu), and nickel (Ni), which are retained in the solid biochar product (Agrafioti et al. 2013). However, activated charcoal that has been approved for use in organic agricultural production is limited to vegetative sources, as stipulated in 7 CFR 205.603. Since activated charcoal's use for organic production does not include activated charcoal from sewage sludge, manure, or other animal products, it is unlikely to contribute heavy metal contamination to the environment (USDA 2002a).

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

The manufacturing of activated charcoal has the potential to cause environmental contamination. The process of manufacturing charcoal also produces bio-oil and syngas, regardless of the production method used (Verheijen et al. 2010, Cox et al. 2012, Hagemann et al. 2018). The bio-oil produced during charcoal production is primarily made up of larger hydrocarbons and tars, while the syngas is made up of small hydrocarbons (e.g., methane [CH_4], ethane [C_2H_6], etc.) and residual steam and carbon dioxide (Verheijen et al. 2010, Kalus et al. 2019). The ratio of these products is dependent on the biomass being processed and the production conditions (Verheijen et al. 2010, Cox et al. 2012). In an effort to recycle products and minimize the production costs associated with fuel and carbon emissions, the syngas is typically collected and condensed into an oil/tar residue and combined with bio-oil products, then burned as combustion fuel to power the charcoal production process, and in some cases, produce electricity (Verheijen et al. 2010).

Most modern charcoal production methods capture these byproducts, which are then either isolated or burned to power the production process (Verheijen et al. 2010). However, if these byproducts were released into the environment, it could result in the contamination of surrounding soil and water systems and the atmosphere (Verheijen et al. 2010). Additionally, carbon dioxide is produced as a component of syngas, and additional carbon dioxide is produced upon the combustion of the syngas and bio-oil byproducts (Wang J et al. 2019).

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

As described above in the "Properties of the Substance" and "Action of the Substance" sections, activated charcoal has a high sorption character that allows it to effectively adsorb a variety of other substances through Van der Waals interactions (Flomenbaum et al. 2002, Silberberg 2003, Olsen 2010, EFSA 2011). Due to its high sorbent capacity, activated charcoal may have interactions with other substances in the treated animal's digestive tract. These substances vary based on the animal and its diet but may include other medicines (e.g., aspirin, atropine) and nutritive supplements, including vitamins and minerals. Since activated charcoal is used for veterinary purposes in organic livestock production, it is unlikely to be introduced in large quantities to the environment as a whole; the most likely way activate charcoal may be introduced to the environment is through deposits in the manure of treated livestock (USDA 2002a).

Activated charcoal is also used as a human medical treatment for a range of toxins (see Table 2), and it has been approved by the FDA for use in many food, beverage, and medicinal products (Flomenbaum et al. 2002, Lapus 2007, Olsen 2010). Given the relatively benign effect of activated charcoal on human health, its approved use for organic agriculture is unlikely to pose a threat to human health (USDA 2002a).

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

As described above in Evaluation Question 7, activated charcoal is unlikely to have interactions outside of the potential adsorption of other substances present in the digestive tract of the treated animal. The administration of activated charcoal to a poisoned livestock animal may result in temporary disruptions to medicines and nutrients present in the animal's digestive tract or consumed by the animal during the treatment period. However, activated charcoal is approved for use as a veterinary treatment and should be only applied as needed, limiting any disruptions in the animal's absorption of medicines, vitamins, and other nutrients to the time of treatment.

As discussed above in Evaluation Question 7, the most likely means of introduction to the agro-ecosytem is through the manure of a treated animal in relatively small quantities (USDA 2002a). The small quantities of activated charcoal potentially deposited via the manure of a treated animal are unlikely to have an effect. Charcoal is also introduced to soil as a soil amendment in the chemically similar form of biochar (Verheijen et al. 2010, Cox et al. 2012, Kalus et al. 2019, Lao and Mbega 2020). The application of biochar has been reported to promote long-term increases in the population of soil microbes due to the porous nature of biochar; this provides microenvironments that foster the growth of microorganisms and protect them from predation (Pietikainen et al. 2000, Warnock et al. 2007, Verheijen et al. 2010, Cox et al. 2012). Several studies have been conducted on the effects of biochar on earthworm populations, however, they show inconsistent results, including negative, neutral, and positive outcomes (Chan et al. 2008, Liesch et al. 2010, Van Zwieten et al. 2010, Verheijen et al. 2010 Cox et al. 2012). This inconsistency is likely due to the variation in biochar properties across feedstocks and production methods coupled with the variation in environmental and soil conditions (Verheijen et al. 2010, Cox et al. 2012).

<u>Evaluation Question #9:</u> Discuss and summarize findings on whether the use of the petitioned 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)).

As discussed in Evaluation Questions 5 and 6, there is the potential for activated charcoal production to be harmful to the environment. Charcoal production may result in the release of bio-oil and syngas byproducts, which include carbon dioxide (Verheijen et al. 2010, Cox et al. 2012, Hagemann et al. 2018). However, activated charcoal is only approved for use as a veterinary treatment for livestock on an as-needed basis (NOP 2018). Given the limited amount and use of activated charcoal in organic livestock production, it is unlikely to be harmful to the environment if used as approved (USDA 2002a).

<u>Evaluation Question #10:</u> Describe and summarize any reported effects upon human health from use of 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)).

Activated charcoal has been hailed as the "universal antidote" for poisoning and is included in the World Health Organization (WHO) Model List of Essential Medicines due to its ability to adsorb toxic compounds while in the gastrointestinal tract following ingestion (Poage et al. 2000, Flomenbaum et al. 2002, Lapus 2007, Olsen 2010, WHO 2019, Zellner et al. 2019). Activated charcoal is commonly applied as a slurry and has been noted to be most effective shortly following ingestion of the toxic compound, within one to three hours. This window may be longer for slow toxins (e.g., opiates, salicylates) (Flomenbaum et al. 2002, Lapus 2007, Olsen 2010, Zellner et al. 2019). As described above in the "Action of the Substance" section, activated charcoal prevents absorption of toxins by the body by adsorbing them in the gut (Flomenbaum et al. 2002, Lapus 2007, Olsen 2010, Zellner et al. 2019).

Activated charcoal treatments are also associated with negative side effects, most commonly emesis (Lapus 2007, Olsen 2010, Zellner et al. 2019). Induced emesis, when coupled with the rare incorrect administration of an activated charcoal slurry, can result in introduction into the lungs, which results in pulmonary complications and possibly death (Flomenbaum et al. 2002, Lapus 2007, Zellner et al. 2019). Activated charcoal treatments have also been linked to constipation and diarrhea, although these side effects may also be due to the ingested toxins (Flomenbaum et al. 2002, Lapus 2007, Zellner at al. 2019).

While activated charcoal has been used as a general treatment for overdoses and ingested toxins, the efficacy of this treatment has come into question in the last 20 years (Olsen 2010, Zellner et al. 2019). This is largely due to the lack of large, quality studies on the efficacy of activated charcoal. These studies are limited due to ethical concern about intentionally administering toxins for treatment and the links to increased emesis upon administration of the substance (Flomenbaum et al. 2002, Zellner et al. 2019). These changes to clinical opinion have resulted in activated charcoal usage being generally limited to cases where the following are true: there is a substantial risk of poisoning, the toxin is still likely in the gastrointestinal tract, and the patient is conscious and able to maintain an open airway (Lapus 2007, Olsen 2010, Zellner et al. 2019).

Activated charcoal can be produced as a fine dust, making it a potential respiratory health hazard and eye irritant (Cox et al. 2012). The substance may pose a dust hazard during production, transport, and application (Cox et al. 2012). When handling activated charcoal dust, appropriate personal protective equipment should be used and the activated charcoal should be watered to dampness to prevent it from becoming airborne (Cox et al. 2012).

Evaluation Question #11: Describe all natural (non-synthetic) substances or products which may be used in place of a petitioned substance (7 U.S.C. § 6517(c)(1)(A)(ii)). Provide a list of allowed substances that may be used in place of the petitioned substance (7 U.S.C. § 6518(m)(6)).

Charcoal is a natural substance with similar chemical and physical characteristics to synthetic activated charcoal (Flomenbaum et al. 2002, USDA 2002a, EFSA 2011, Cox et al. 2012, Anderson et al. 2013, Verheijen et al. 2010, Hagemann et al. 2018, Kalus et al. 2019, Wang J et al. 2019). Charcoal is also formed through thermal degradation processes and acts as a precursor to activated charcoal, as described previously in Evaluation Question 2. The major differentiation between these substances is the activation process, which dramatically enhances surface area of the substance (Flomenbaum et al. 2002, USDA 2002a, Marsh and Reinoso 2006, Hagemann et al. 2018). The large surface area of activated charcoal is primarily responsible for its high sorption character. Therefore, while natural charcoal will have sorption character, it will be less effective at adsorbing toxins than activated charcoal and would therefore be a less effective veterinary treatment.

Bentonite is a natural mineral with high sorption character that is found within kaolin clay deposits (USDA 1995, NOP 2016c, Mgbeahuruike et al. 2018). Bentonite may also include other minerals, such as montmorillonite, quartz, feldspar, gypsum, pyrite, kaolinite, dickite, narcite, halloysite, and metahalloysite (USDA 1995, USDA 2002b, Mgbeahuruike et al. 2018). Bentonite may also be administered for treatment of toxins and follows a mode of action similar to activated charcoal by adsorbing toxins from the digestive tract (Mgbeahuruike et al. 2018, Lao and Mbega 2020). Bentonite has also shown reportedly positive results when used as an animal feed additive, improving animal weight gain and egg quality. Additionally, Mgbeahuruike reported bentonite to be a more effective food additive than activated charcoal, offering greater protection against poultry feeds contaminated with aflatoxin (Mgbeahuruike et al. 2018).

Kaolin pectin is a synthetic substance that has been approved by the USDA NOP for use in organic livestock production "as an adsorbent, antidiarrheal, and gut protectant" in 7 CFR 205.603. Kaolin pectin is a synthetic substance formulated by the combination of natural kaolin minerals with synthetic pectin, a sugar polymer extracted from edible plant materials. The primary use of kaolin pectin in organic livestock production is as an antidiarrheal because of ability of the combination of the kaolin minerals and pectin polymer to hold water (USDA 2002b). However, the adsorbent character of kaolin pectin, which is primarily due to the kaolin minerals described above, may provide an alternative to activated charcoal for treatment of livestock that have ingested toxic substances.

Evaluation Question #12: Describe any alternative practices that would make the use of the petitioned substance unnecessary (7 U.S.C. § 6518(m)(6)).

Activated charcoal is approved for organic livestock production limited to veterinary use on an as-needed basis (NOP 2018). As discussed in the "Specific Uses of the Substance" and "Action of the Substance" sections, the primary use of activated charcoal within livestock production is as a treatment when an animal has ingested a toxic substance. Therefore, the best alternative practice is to remove toxic substances and plants from the agro-ecosystem. Since toxins may also be introduced through animal feeds that were contaminated in processing or storage, proper feed storage that eliminates the potential for mold and fungal growth provide another means to avoid the administration of activated charcoal (Oluwafemie et al. 2014, Mgbeahuruike et al. 2019, Lao and Mbega 2020).

Orogastric lavage is an alternative to the administration of activated charcoal to remove ingested toxins. In this practice, a tube is inserted into the patient's mouth and run into the stomach. It is then used to remove the contents of the stomach, including the toxins. During the procedure, the patient is also administered saline solution via a gastric syringe or funnel (Flomenbaum et al. 2002). Like activated charcoal, orogastric lavage treatments are time dependent, and they are most effective when performed within one hour of ingestion of the toxin (Flomenbaum et al. 2002, Lapus 2007, Olsen 2010, Zellner et al. 2019). Orogastric lavage treatments may be followed by application of an activated charcoal slurry through the lavage tube to enhance toxin removal, removing any toxins missed by the lavage and promoting the removal of toxins previously absorbed through passive diffusion (Flomenbaum et al. 2002). Orogastric lavage has potential for negative side effects, including injury to the airway, esophagus, and stomach; severe hypernatremia; and aspiration pneumonitis. It is only recommended when it can be applied shortly after ingestion of life-threatening amounts of toxic substances (Flomenbaum et al. 2002).

Report Authorship

The following individuals were involved in research, data collection, writing, editing, and/or final approval of this report:

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All individuals are in compliance with Federal Acquisition Regulations (FAR) Subpart 3.11—Preventing Personal Conflicts of Interest for Contractor Employees Performing Acquisition Functions.

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