Activated Charcoal

Handling/Processing

Identification of Petitioned Substance

Chemical Names:
activated charcoal; activated carbon

Other Names:
activated biochar; granular carbon for water treatment; pelletized catalyst carbon; powdered decolorizing carbon

Trade Names:
Acticarbone; AquaCarb; Cabot; Haycarb; Kuraray Coal; Norit; VOCarb; numerous others

CAS Numbers:
7440-44-0 (carbon; sometimes attributed to activated carbon);
16291-96-6 (charcoal);
64365-11-3 (activated charcoal)

Other Codes:
EC No. 931-328-0 or 264-846-4;
EINECS 231-153-3;
UNII 2P3VWU3H10

Summary of Petitioned Use

This full scope technical report provides updated information to the National Organic Standards Board (NOSB) to support the sunset review of activated charcoal, listed at 7 CFR 205.605(b)(2). This technical report focuses on uses of activated charcoal in organic processing and handling as a filtering aid (as specified in the annotation for this material).

Canandaigua Wine originally submitted a petition for activated charcoal in 2002, for use as a processing aid to absorb excess brown color pigments from white grape juice concentrate (Canandaigua Wine, 2002). After reviewing the material, the NOSB Processing Committee (now the Handling Subcommittee) considered activated charcoal to be synthetic, due to chemical processing steps involving acids and bases (NOSB, 2002). The committee determined that other filtering aids on the National List were not viable alternatives for the petitioned use (NOSB, 2002). Based on the NOSB's recommendation, activated charcoal was added to the National List of Allowed and Prohibited Substances (hereafter referred to as the "National List") in 2006 (71 FR 53299) with the following annotation: "Activated charcoal (CAS #s 7440–44–0; 64365–11–3)—only from vegetative sources; for use only as a filtering aid."

While activated charcoal can also come from non-vegetative sources (NOP, 2002), in this report we focus only on the vegetative sources specified in the annotation.

For the remainder of the report, we will refer to activated charcoal as "AC."

Characterization of Petitioned Substance

Composition of the Substance:

AC is often referred to as activated carbon in literature. It is composed of up to 90% carbon with oxygen, hydrogen, sulfur, and nitrogen occurring as atoms or in functional groups (Heidarinejad et al., 2020). The choice of activation agent largely determines the occurrence of carboxyl, carbonyl, phenol, lactone, ether, and quinone functional groups (Heidarinejad et al., 2020; Henning & von Kienle, 2021). The occurrence of these functional groups in turn affects the adsorption capacities achieved via activation. Fissures and pores lend AC its vast available surface area and significant adsorption ability (Henning & von Kienle, 2021).

The distinctions between charcoal, AC (or carbon), and biochar are not always clearly defined. In general, they are all produced from thermochemical conversion of carbonaceous feedstocks in the absence of oxygen or other oxidants, but the context of their usage often determines the naming convention. For example, carbonized (alternately pyrolyzed) substances used for soil amending or remediation are often referred to as biochar, but when burned as fuel they may be simply known as charcoal (Hagemann et al., 2018). Further, the carbonization of carbon-based materials results generally in "char," while the carbonization of specifically plant-based carbonaceous biomass results in "biochar" (Kalus et al., 2019; Park et al., 2013). When used as an adsorbent to remove contaminants from liquids or gases, these materials are known as AC or activated carbon (Hagemann et al., 2018).

AC is a form of microporous carbon known as pyrogenic carbonaceous material (Hagemann et al., 2018; Marsh & Rodríguez-Reinoso, 2006). In general, microporous carbons consist of a complex arrangement of carbon atoms, some in hexagonal configurations and some as individual atoms bonded closely but not in a close-packed arrangement (Marsh & Rodríguez-Reinoso, 2006). This arrangement creates space between all of the internal carbon structures so that every void is connected to every other, resulting in enormous internal surface area (Marsh & Rodríguez-Reinoso, 2006). The interconnected voids, known as "adsorption sites," may be widened or narrowed by physical or chemical processes to achieve the intended adsorption characteristics. This process is known as "activation." (Marsh & Rodríguez-Reinoso, 2006).

The activation process may include physical methods ("thermal"), chemical methods, or a combination (Hagemann et al., 2018; Heidarinejad et al., 2020; Marsh & Rodríguez-Reinoso, 2006). Manufacturers employ a wide variety of activation agents depending on the intended use of the material. Although zinc chloride and phosphoric acid are the most prevalent, other activation agents include (Hagemann et al., 2018; Heidarinejad et al., 2020; Henning & von Kienle, 2021; Marsh & Rodríguez-Reinoso, 2006):

- gases (steam, carbon dioxide, oxygen, nitrogen)
- acids (phosphoric, sulfuric, nitric, hydrochloric)
- bases (potassium hydroxide, sodium hydroxide, sodium carbonate, potassium carbonate)
- metal chloride salt solutions (zinc chloride, iron chloride, calcium chloride)
- urea

Commercial forms of AC contain approximately 0.1-20% ash, generally consisting of (Henning & von Kienle, 2021):

- carbonate or phosphate salts of alkali or alkaline earth metals
- silica
- iron
- aluminum oxide

The wide range of these ash impurities results from different feedstocks, and whether or not the material was water or acid-washed (Henning & von Kienle, 2021; Marsh & Rodríguez-Reinoso, 2006). For example, AC derived from coconut shells has a far lower ash content than that derived from coal (Marsh & Rodríguez-Reinoso, 2006). AC itself is typically acidic, or rarely basic (Henning & von Kienle, 2021).

Source or Origin of the Substance:

Any carbonaceous material can be manufactured into AC if the carbon content is high enough (Mohammad-Khah & Ansari, 2009). Most commonly, wood, charcoal, nut shells, fruit pits, coal, lignite, peat, bone, and paper mill waste are the feedstocks, but synthetic polymers like PVC may also be used (Mohammad-Khah & Ansari, 2009). The most common raw material is coconut shells, but research into new feedstocks has accelerated in recent years (Román Suero et al., 2017). Given the National List annotation, this report will only focus on those sources derived from plant material.

Properties of the Substance:

AC is a highly flammable substance that is tasteless and odorless (see **Table 1**). Manufacturers sell AC as powders, granules, or formed cylindrical or spherical pellets (Henning & von Kienle, 2021). The material is black due to the pyrolysis and subsequent carbonization of the raw materials.

AC's pore volume exceeds 25 $cm^3/100$ g, leading to a remarkable inner surface area of 500-2000 m^2/g (Henning & von Kienle, 2021; Mohammad-Khah & Ansari, 2009). The pores in activated carbon are categorized as *micropores* (less than 2 nm), *mesopores* (between 2 and 50 nm), and *macropores* (greater than 50 nm) (Chatterjee & Saito, 2015). As a hydrophobic substance, AC is particularly useful for the adsorption of nonpolar organic substances (Henning & von Kienle, 2021), such as fuel oil, various solvents, and polychlorinated biphenyls (U.S. EPA, 2012). For further information on adsorption properties and characteristics, see *Action of the Substance* below.

Since so many different combinations of raw materials and activation agents may be used in the production of AC, it is difficult to definitively describe distinct chemical properties and textural and surface characteristics, particularly porosity (Román Suero et al., 2017). Specific porosity characteristics, and thus adsorptive properties, are determined by the cellulose, hemicellulose, and lignin contents of the raw materials prior to pyrolysis, as well as temperature, duration of heating, and the activation agent used (Arriagada et al., 1997; Cagnon et al., 2009; Chatterjee & Saito, 2015; Rodriguez Correa et al., 2017; Román Suero et al., 2017). Materials higher in lignin result in AC with higher total porosity and surface area (Chatterjee & Saito, 2015). Lignin-based substances also yield a greater proportion of micropores upon activation compared to cellulose-based chars, which activate more easily and yield a greater pore size variety (Chatterjee & Saito, 2015).

Though there is great variability in porosity characteristics depending on production practices, in general micropores constitute 95% of the surface area while mesopores and macropores make up the other 5% (Bansal & Goyal, 2005; El Gamal et al., 2018). Macropores serve more as connections for the passage of molecules to the smaller pore sites than as adsorptive sites themselves (Bansal & Goyal, 2005; El Gamal et al., 2018).

AC exhibits a great variety of chemical and physical properties depending on production practices, and some values in **Table 1** only represent pure elemental carbon.

Table 1: Properties of AC. Information taken from the National Center for Biotechnology Information, 2023

Property	Value
Physical State and Appearance	Powder or pellets
Odor	Odorless
Taste	Tasteless
Color	Black
Molecular Weight (g/mol)	Approx. 12.011
Density (g/cm^3)	0.08-0.5 (varies with source)
pH	Depends on source, manufacture, and activation
Solubility	Insoluble in water and organic solvents
Boiling Point (°C)	As pure carbon, >4000
Melting Point (°C)	As pure carbon, >3500
Vapor Pressure (mm/Hg)	Effectively 0
Stability	Adsorbs vapor from air
Reactivity	Highly flammable; dust is explosive

The variety of feedstocks used to produce AC have different properties and lead to different textures and porosity characteristics in the AC prepared from them (see **Table 2**).

Table 2: Composition of feedstocks and textural attributes of AC prepared from them. Adapted from Marsh & Rodríguez-Reinoso (2006)

Feedstock	Carbon (wt%)	Volatiles (wt%)	Density (g/cm^3)	Ash (wt%)	Texture and pore volume of AC
Soft wood	40-50	55-60	0.4-0.5	0.3-1.1	Soft, large pore volume
Hard wood	40-42	55-60	0.55-0.80	0.3-1.2	Soft, large pore volume
Lignin	35-40	58-60	0.3-0.4	-	Soft, large pore volume
Nutshells	30-45	55-60	1.4	-	Hard, large micropore volume
Lignite	55-70	25-40	1-1.35	5-15	Hard, small pore volume

Specific Uses of the Substance:

AC has dozens of uses in food production, pharmaceutical processes, water treatment, and industrial pollution management (Henning & von Kienle, 2021; Marsh & Rodríguez-Reinoso, 2006). In food processing, AC is a common filtering aid used to remove impurities affecting appearance, taste, and odor (Henning & von Kienle, 2021). Processed foods and beverages require large volumes of water for the production process and for in-product use (EPA, 2017). AC filtration is an important step in the production of alcoholic beverages, fruit juice, oils, and vinegar (see **Table 3**).

Table 3: Foods and beverages commonly filtered with AC

Food/beverage product	Targeted modification	References
Alcoholic spirits	Taste; Odor; Haziness	(Labbé et al., 2006; Rodríguez-Reinoso, 2002)
Beer	Taste	(Rodríguez-Reinoso, 2002)
Decaffeinated coffee	Caffeine Content	(Henning & von Kienle, 2021; Rodríguez-Reinoso, 2002)
Feed Water for Processed Foods and Beverages	Taste; Odor; Chlorine Content	(Rodríguez-Reinoso, 2002)
Fruit juice	Color	(Arslanoğlu et al., 2005; Henning & von Kienle, 2021)
Plant and Fish Oils	Color; Odor	(Gharby, 2022; Guliyev et al., 2018)
Sugars and sweeteners	Color	(Ahmedna, 2000; Rodríguez-Reinoso, 2002)
Vinegar	Taste; Color	(López et al., 2003)
Wine	Taste; Odor; Color	(Rodríguez-Reinoso, 2002; Waterhouse et al., 2016)
Yeast extract	Taste; Color	(Rodríguez-Reinoso, 2002)

The processed food and beverage industry commonly uses granular and powdered AC. Processors use granular AC for large volume and continuous flow processes. Powdered AC is the preferred form for batch processes (Henning & von Kienle, 2021; Iwuozor et al., 2023; López et al., 2003).

The decolorization of sugar frequently involves both granular and powdered AC. Manufacturers use AC in different ways to decolorize sugar (Bansal & Goyal, 2005). The method used often depends on the scale of the operation and economic factors (Bansal & Goyal, 2005). The standard dosage rate is 3-4 kg AC per ton of raw sugar (Iwuozor et al., 2023).

Winemakers add powdered AC to wine at a rate of 0.05-1 g AC per liter of wine. Brandy producers use dosing rates of 5 g, and upwards of 30 g AC per liter for substantial flavor modification. Beer producers, like wine producers, generally favor the smallest effective dose to minimize loss of flavor quality. A range of 2-2.5 g AC per liter of beer is a common dosing range prior to bottling, although a higher dose may be applied to poor quality beer at the cask stage (Bansal & Goyal, 2005).

Bleaching clay (e.g., bentonite) is the most common adsorbent used for edible oil production (Gharby, 2022). Producers may add AC to bleaching clay as a cost-effective measure to obtain a higher adsorption capacity (Bansal & Goyal, 2005; Gharby, 2022). These mixtures require 5-10 g AC per 100 g bleaching clay (Gharby, 2022).

In the vinegar industry, producers commonly decolor a portion of the vinegar with powdered AC and blend it with a larger volume of colored vinegar to achieve the desired quality standard (López et al., 2003). Decolorizing vinegar with AC can require dose rates of 10-20 g AC per liter of vinegar (Achaerandio, 2002; López et al., 2003).

Drinking water is commonly filtered with AC. Water treatment facilities in the U.S. use both granular and powdered AC, although powdered AC is more common (National Research Council Safe Drinking Water Committee, 1980). Drinking water may undergo additional filtration steps once within the production facility. Breweries, for example, commonly subject incoming drinking water to additional treatment prior to becoming dilution or brew water, both of which will often undergo dechlorination by granular AC (Eumann & Schildbach, 2012).

Approved Legal Uses of the Substance:

The regulatory history of AC is difficult to interpret and identify. The threads describing the regulatory status and history of AC are sometimes buried in the Federal Register, which isn't searchable by term prior to 1994.

AC has several applications in the drug, food, and cosmetics industries, including use as a (Anderson, 2019):

- medicine
- filter
- pH control agent
- food dye

When produced from vegetative sources, AC is an allowed synthetic, for use as a filtering aid in organic production. As a filtering aid, the Food and Drug Administration (FDA) and the Alcohol and Tobacco Tax and Trade Bureau (TTB) both regulate AC. The FDA regulates the use of food additives, while the TTB regulates the use of filtering aids used to make certain alcoholic substances, or juices that are used in alcoholic beverage production. While not falling within the scope of organic handing, the EPA considers AC to be a "best technology treatment technique" for removing organic contaminants in drinking water filtration systems (40 CFR 141.61).

FDA

When used as a filtering aid, AC *could* be considered a food additive by the FDA, as defined at 21 CFR 170.3(e)(1). However, AC is not listed in any sections within 21 CFR specific to juice, juice filtration, or as a food additive in related applications.

Under the Federal Food, Drug, and Cosmetic (FD&C) Act, manufacturers are required to obtain premarket approval for new uses of food additives (Gaynor & Cianci, 2006). Substances that are *Generally Recognized as Safe* (GRAS) for specific uses are excluded from the definition of a food additive under the FD&C Act (Gaynor & Cianci, 2006). As such, GRAS substances do not require premarket approval by the FDA for those specific GRAS uses (Gaynor & Cianci, 2006). Unlike food additive safety determinations, which are made by the FDA, GRAS determinations can be made by non-governmental experts (Gaynor & Cianci, 2006). In 2016, the FDA published an updated Final Rule on GRAS substances, which amended the rule so that the GRAS notification program was voluntary (81 FR 54960-55055). The notification program provides a mechanism for a company (or a person) to notify the FDA that a substance is GRAS. However, as the notification is now voluntary, identifying whether a substance is or is not considered GRAS by some experts (such as within food manufacturing businesses) may not always be possible. Furthermore, not all previous GRAS determinations are easily searchable.

Under a contract between the FDA and the Life Sciences Research Office (LSRO), the Select Committee on GRAS Substances (SCOGS; consultants working under the FDA-LSRO contract) reviewed activated carbon (AC) in 1981 (Center for Food Safety and Applied Nutrition, 2018; Federation of American Societies for Experimental Biology, 1981), and noted that it was GRAS for several uses (see **Table 4**, below). These include uses in the purification of various foods, juices, and wines. While we were unable to locate a Federal Register notice confirming that the FDA had affirmed the GRAS status, presentation materials from an FDA official indicate that AC is considered GRAS by the FDA as a processing aid based on the 1981 SCOGS report (Anderson, 2019). Two separate sets of presentation materials by FDA officials indicate that AC is not approved for use as a color additive (Anderson, 2019; Overbey, 2022).

Table 4: Food uses of activated carbon (AC). Adapted from Federation of American Societies for Experimental Biology, 1981, and updated with information from 27 CFR 24.246.

Use	Limitations	Authorization	Notes
Decolorization of sugar	Carbon sources: bone, blood, and plants.	McLaughlin, 1967	prior-sanctioned listing
Water purification in brewing and soft-drink industries; decolorization and other purification purposes in brewing industry	_	Larsen, 1978	unpublished GRAS
Purification of various foods including gelatin, oil, fats, sorghum syrups, and fruit juices	_	Larsen, 1978	unpublished GRAS
Removing color from wine and/or juice from which wine is produced; to clarify and purify wine and/or juice	Maximum level of use, 25 lb/1000 gallons of wine, unless authority in excess of this amount is granted from the TTB.	TTB: 27 CFR 24.241; § 24.242	Must meet the specifications in the Food Chemicals Codex and be removed, as stated in an FDA advisory opinion, dated January 26, 1979.
Assisting precipitation during fermentation		TTB: 27 CFR 24.176, § 24.246	Must meet the specifications in the Food Chemicals Codex and be removed, as stated in an FDA advisory opinion, dated September 8, 2016.

TTB

The Alcohol and Tobacco Tax and Trade Bureau (TTB) regulates the use of filtering aids used to produce wine and juice (see **Table 4**, above). The TTB regulations describing the use of AC include 27 CFR 24.241, § 24.242, and § 24.246. In short, the TTB states that activated carbon can be used to decolorize juice or wine. Limitations include that the wine will retain a “vinous character,” and that the quantity of activated carbon may not exceed 25 pounds per 1,000 gallons of wine (3.0 grams/liter). When a proprietor wishes to use more than 25 pounds of activated carbon, they must provide the TTB written notice, and gain permission. AC can be used to assist in precipitation during fermentation, clarification, purification, and decolorization of juice or wine.

Action of the Substance:

Adsorption is the process by which a solid, the adsorbent, accumulates gaseous or dissolved substances, adsorbates, on its surface (Henning & von Kienle, 2021). The adsorptive behavior of AC cannot be described by its extensive porosity and surface area alone (Bansal & Goyal, 2005). The chemical structure of AC influences interactions with polar and nonpolar substances as well; for example, defects in the three-dimensional lattice structure of AC at the surface produces highly reactive carbon atoms (Bansal & Goyal, 2005). The adsorptive action differs depending on the method of production and any activation agents used (Bansal & Goyal, 2005).

AC may adsorb other materials physically (physisorption), a process that generally relies on weak, non-bonding electrostatic charges known as van der Waals forces (Henning & von Kienle, 2021). Chemical adsorption (chemisorption) also occurs which results in a stronger attachment resulting from chemical modification of the adsorbed material or adsorbent (Henning & von Kienle, 2021). Since physisorption is based on electrostatic forces, it is not substance-specific; these forces act on any adsorbent/adsorbate system (Bansal & Goyal, 2005). Chemisorption is substance-specific since it relies on the chemical bonding potential of materials (Bansal & Goyal, 2005). Liquid phase adsorption is far slower than gas phase adsorption (Henning & von Kienle, 2021).

The largely random arrangement of carbon sheets and amorphous carbon in AC leads to variation in the electron clouds and unpaired electrons, greatly influencing the reactivity and adsorptive potential (Bansal & Goyal, 2005).

Acidic functional groups in AC, including those associated with carbon-oxygen bonds, adsorb metal ions like lead, cadmium and mercury through the formation of complexes (Bansal & Goyal, 2005; Mohammad-Khah & Ansari, 2009). In higher pH solutions, these carbon-oxygen groups tend to ionize, resulting in a negative charge that adsorbs positively charged metal ions. In low pH conditions, surface groups protonate and the carbon graphene sheets in the structure act as bases, creating sites for the formation of complexes with dissolved organic compounds (Bansal & Goyal, 2005). Organic compounds are also adsorbed through interactions related to hydrogen bonding, electrostatic charges, and dispersion forces (Bansal & Goyal, 2005). Furthermore, the molecular size of organic compounds relates to how they interact with AC. Pore size variation of the AC may determine which compounds it can adsorb since micropores may not be large enough for some large molecules to pass through (Bansal & Goyal, 2005).

Carboxyl functional groups on the surface adsorb water vapor and AC varieties engineered to contain a high proportion of carboxyl groups are used in humidity removal (El Gamal et al., 2018). Various sulfur-attracting functional groups adsorb volatile sulfur compounds (El Gamal et al., 2018). The entire system can be extremely complex and variable and cannot be completely described in this report. Several books of significant length have been authored on the subject, including Bansal and Goyal (2005) and Marsh & Rodríguez-Reinoso (2006), cited throughout this report. Additional technical information that is beyond the scope of this report can be obtained from those sources.

Combinations of the Substance:

Granular and powdered AC, the forms commonly used in food and beverage processing, both go through crushing and sieving steps to achieve the desired consistency prior to activation. No additional ingredients are introduced to the AC source material during these steps (Rodríguez-Reinoso, 2002). Producers commonly refine plant oils with bentonite in combination with AC (Gharby, 2022).

Manufacturers can activate AC both physically and chemically (see *Composition of the Substance*). Chemicals (e.g., phosphoric acid) added during the activation step are generally removed via a recovery step after the dehydration reaction is complete (Henning & von Kienle, 2021; Rodríguez-Reinoso, 2002).

Researchers have demonstrated AC can be further modified by reinforcing the surface with organic or inorganic chemicals post-activation to increase the affinity of the AC for particular chemical targets (Kiruba et al., 2015; Rashid & Bezbaruah, 2020; Rodríguez-Reinoso, 2002). Current industrial applications for reinforced AC products are generally focused on wastewater treatment (Jha et al., 2021; Kiruba et al., 2015; Rashid & Bezbaruah, 2020). We found no data suggesting reinforced AC products are common in food and beverage processing, and experimental evidence suggesting future applications is very limited. Cansado et al. (2022) demonstrated the effective removal of odor-tainting compounds (4-ethylphenol and 4-ethylguaiacol) from ethanol-containing wine-like fluids using commercial ACs chemically modified and reinforced with either nitric acid or sodium hydroxide.

Status

Historic Use:

There is evidence that the Sumerians used charcoal for water purification as early as 3000 BCE. The Egyptians (2000 BCE), Indus Valley cultures (1500 BCE), Israelites (1550 BCE), and Greeks (400-300 BCE) also used charcoal for this purpose (Smith, 2017).

In 1785, the Russian chemist Lowitz documented the decolorization of tartaric acid with wood charcoal. Further research in the same laboratory documented decolorization of oil, alcohol, and honey in 1793 (Deitz, 1944). By 1794 an English sugar refinery was successfully decolorizing sugar with wood charcoal and by 1808 it was common practice across Europe. The first AC produced on a commercial scale was a powdered wood charcoal in 1909. The manufacturing process was adapted from a patent held by the Swedish chemist von Ostreijko (Çeçen & Aktaş, 2011). The first application of this particular form of AC for decolorizing sugar was also in 1909 (Deitz, 1944).

Commercial scale production of AC in the United States did not occur until 1913 (Çeçen & Aktaş, 2011). Food and beverage processing applications for AC began to notably expand beyond sweetener processing (corn syrup, cane, and beet sugars) in the late 1920's and throughout the 1930's. It is during this period that decaffeination of coffee and the decolorization of vegetable oils using AC begin to appear in scientific literature. Powdered AC was used by Chicago meat packers for taste and odor control beginning in 1928. The removal of undesirable flavors and decolorization using AC filtration for alcoholic spirits, beer, and wine was also of research interest during this period (Deitz, 1944).

A discussion of AC filtration for water treatment specifically in food processing plants appears in Brewer's Digest in 1941 (Deitz, 1944). By the latter half of the twentieth century, granular and powdered AC were common materials for drinking water treatment (National Research Council Safe Drinking Water Committee, 1980). By 1994, drinking water treatment had displaced sweetener decolorization as the largest end-use market for activated carbon (Rodríguez-Reinoso, 2002).

Organic Foods Production Act, USDA Final Rule:

OFPA (1990) does not include any reference to AC.

For processing and handling purposes, USDA organic regulations include AC (CAS 7440-44-0 and 64365-11-3) on the National List (7 CFR 205.605(b)(2)). The annotation specifies that AC must be from vegetative sources, and that it is only for use as a filtering aid. AC was originally petitioned in 2002 (Canandaigua Wine, 2002), and added to the National List in 2006 (71 FR 53299).

USDA organic regulations also include AC (CAS 7440-44-0) for use in livestock production (7 CFR 205.603(a)(6)). Under these regulations, it must be from vegetative sources, and is allowed for use as a medical treatment.

International:

AC is allowed under several other international organic standards (see Table 5, below). While all of these standards allow AC as a processing aid, they include small variations in source and use restrictions.

Table 5: Allowance of AC in processing and handling applications under a selection of international organic standards

Standard	Applicable regulations	Allowed?	Source and use restrictions (if applicable)
Canada Organic Standards (CAN/CGSB 32.311-2020)	PSL Table 6.3, Ingredients classified as food additives; PSL Table 6.5, Processing aids.	Yes	Shall be of plant origin. Prohibited for use in the production of maple syrup.
European Union Organic Standards (EU No. 2021/1165)	Annex V Part A: Authorised food additives and processing aids referred to in point (a) of Article 24(2) of Regulation (EU) 2018/848, Section A2 – Processing aids and other products, which may be used for processing of ingredients of agricultural origin from organic production.	Yes	CAS 7440-44-0. Allowed for the processing of products of plant and animal origin.
Japanese Agricultural Standard for Organic Processed Foods	Appended Table 1-1, Additives (Organic processed foods other than organic alcohol); Appended Table 1-2, Additives (Organic alcohol beverages).	Yes	Limited to the use in processed products of plant origin; also beverages.
Codex Alimentarius Commission—Guidelines for the Production, Processing, Labelling and Marketing of Organically Produced Foods (GL 32-1999)	Table 4: Processing aids which may be used for the preparation of products of agricultural origin referred to in Section 3 of these guidelines.	Yes	-
IFOAM-Organics International	Appendix 4—Table 1: List of approved additives and processing/post-harvest handling aids.	Yes	Synthetic forms are allowed if organic or natural sources are not commercially available. May be used as a processing or a post-harvest handling aid.

Evaluation Questions for Substances to be used in Organic Handling

Evaluation Question #1: 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)).

For the purposes of this report, it would be impossible to summarize every specific AC manufacturing process used to produce the petitioned substance. According to Henning and von Kienle (2021), over 1,500 manufacturing patents currently exist globally (as of 2021). General summaries will be provided here to represent the principles of AC manufacturing.

Carbonization

While the terms *pyrolysis* and *carbonization* are often used interchangeably, they are not definitively the same (Devi et al., 2021).

- Pyrolysis refers to a chemical decomposition resulting from elevated temperatures, typically between 300-800 °C, yielding various gaseous fuels, carbon dioxide, carbon monoxide, water vapor, nitrogen, and solid carbon.
- Carbonization is the process by which the carbon content of a material is concentrated, occurring at higher temperatures of 800-2000 °C which produces carbon-carbon bonds.

In this way, pyrolysis can be thought of as the path to carbonization (Devi et al., 2021). Generically, both feature thermally induced decomposition of carbonaceous feedstocks in the absence of oxygen, but the target products are different. Pyrolysis is used to produce and collect specific substances according to industrial relevance like tars, volatile organic compounds, or char with associated impurities. Carbonization is used to concentrate and produce a carbon material with higher purity (Devi et al., 2021).

The production of AC begins with production of porous carbon by pyrolysis of the feedstock, followed by carbonization (see **Figure 1**) to further reduce tars and other volatile substances in the pore spaces while largely preserving the structure of the material (Devi et al., 2021). The initial production of char typically occurs at a temperature less than 1000 °C, since higher temperatures tend to fuse or destroy the microporous nature, although this may be desired depending on the intended application of the final product (Devi et al., 2021; Marsh & Rodríguez-Reinoso, 2006).

Although all carbonaceous materials develop a microporous character upon carbonization to char, their adsorptive capacity is typically not sufficient for commercial filtering applications (Marsh & Rodríguez-Reinoso, 2006). Physical activation (sometimes referred to as gas activation, thermal activation, or gasification) with steam or carbon dioxide and chemical activation with other aqueous substances may be used to increase the porosity and optimize the AC for specific applications (Marsh & Rodríguez-Reinoso, 2006).

Most commonly, manufacturers use rotary kilns to produce AC, but they may also use multiple hearth furnaces, vertical shaft furnaces, and fluidized bed furnaces (Henning & von Kienle, 2021).

- Rotary kilns are narrow rotating barrels oriented horizontally with several burners and gas supply lines along their length, allowing for control over the activation rate (See **Figure 2**) (Henning & von Kienle, 2021). Rotary kilns sometimes feature long residence times, with manufacturers leaving material in the kilns for up to several days (Wigmans, 1989).
- Vertical shaft furnaces are 5-8 meter high chambers lined with refractory bricks (Henning & von Kienle, 2021). Some contain directional gas inlets and exhaust removal systems (Henning & von Kienle, 2021).
- Multiple hearth furnaces are typically vertical shafts of separate stacked chambers each with rotating arms (Henning & von Kienle, 2021). Feedstocks enter through the top and fall through openings in each chamber (which may have different operating conditions) (Henning & von Kienle, 2021). Residence time can be hours (Wigmans, 1989).
- Fluidized bed furnaces, somewhat simplified, are chambers jacketed with refractory materials in which hot gases are injected through powdered solids, causing them to behave as fluids

(Myöhänen, 2011). These offer fast heat transfer and short residence time (minutes) (Henning & von Kienle, 2021; Wigmans, 1989).

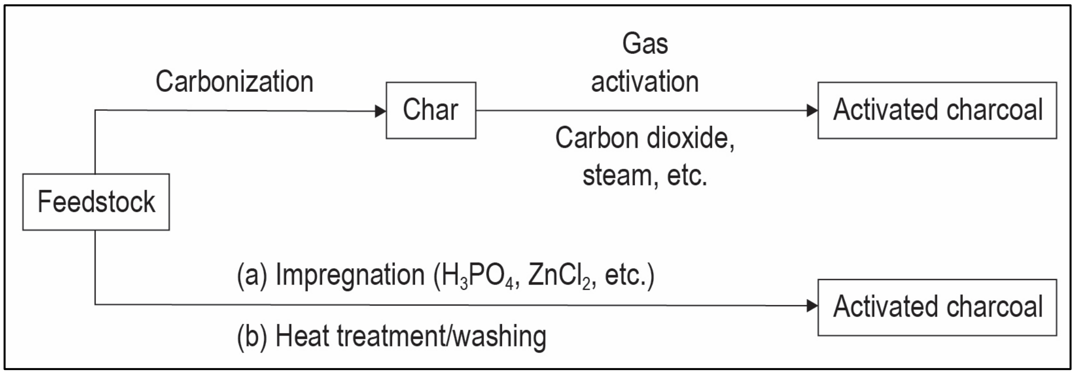

Figure 1: Generalized manufacturing processes for AC. Gas activation is sometimes referred to as physical activation or gasification. The lower branch represents chemical activation. The development of a porous structure is initiated by the chemical impregnation during pre-treatment. While some level of carbonization does occur in the lower branch, the temperatures are significantly lower and result in incomplete carbonization so we have retained the term "heat treatment" from the original source material rather than "carbonization." Adapted from Marsh and Rodríguez-Reinoso (2006).

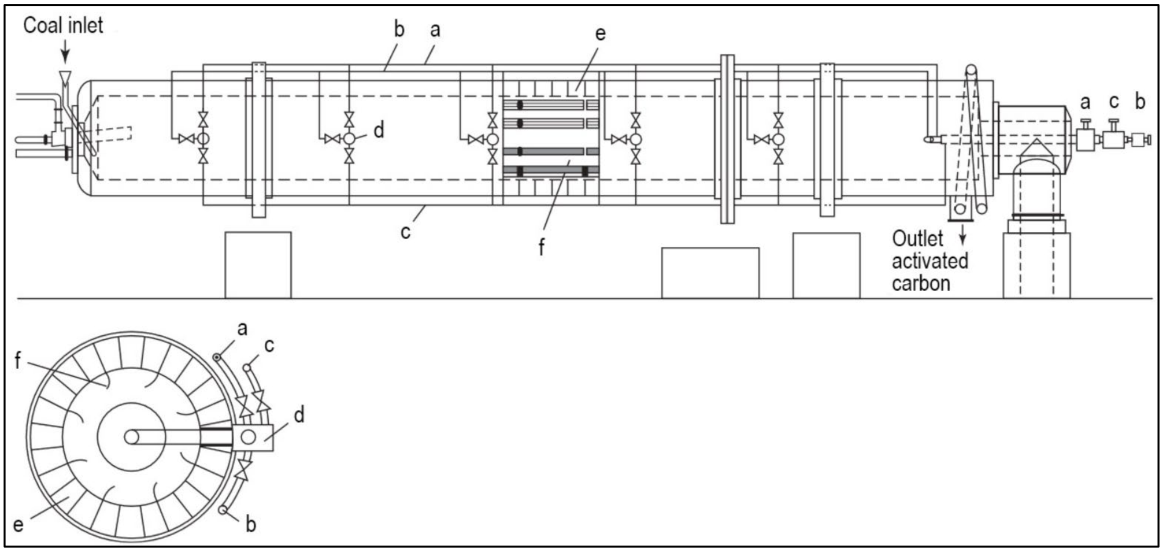

Figure 2: Rotary kiln for AC production. (a) steam; (b) gas; (c) air; (d) burner; (e) brick lining; (f) lifters. Adapted from Henning and von Kienle (2021)

Physical activation

Heating carbonaceous feedstocks in the presence of oxygen results in combustion, releasing carbon into the air as carbon dioxide, so physical activation requires the exclusion of air (Mohammad-Khah & Ansari, 2009). Typically steam, carbon dioxide, or a mixture of the two are used to allow for control of oxidation rates because these are weaker oxidizers than oxygen gas (Henning & von Kienle, 2021). Oxygen reacts with carbon approximately 100 times faster than carbon dioxide and steam (Henning & von Kienle, 2021; Wigmans, 1989).

Manufacturers may pulverize the raw materials or pre-shape them into briquettes or pellets with or without binders consisting of tar, lignosulfonic acids, phenols, or aldehydes prior to activation (Henning & von Kienle, 2021).

Physical activation occurs in furnaces at temperatures between 800-1000 °C, but feedstocks may be pyrolized at 400-500 °C as a pretreatment to reduce the amount of volatile compounds (Henning & von Kienle, 2021; Marsh & Rodríguez-Reinoso, 2006; Mohammad-Khah & Ansari, 2009).

Physical activation can initiate chemical changes to the material (Hagemann et al., 2018). Steam and carbon dioxide penetrate the pore spaces to volatilize substances within (Hagemann et al., 2018). At typical operating temperatures, water and carbon dioxide oxidize (a chemical process) carbonaceous material as well, leading to reactive oxygen groups on the surface (Hagemann et al., 2018). This controlled oxidation leads to some of the chemisorptive properties discussed in *Action of the Substance*, since oxygen participates in various surface functional groups (Marsh & Rodríguez-Reinoso, 2006).

When heated to 200-400 °C, the feedstocks release carbon dioxide (CO_2) from the decomposition of carboxylic groups (Arriagada et al., 1997). At 700 °C, the feedstocks release carbonates (Arriagada et al., 1997). At 900 °C, the feedstocks release carbon monoxide gas due to the decomposition of carbonyl, quinone, and phenol groups (Arriagada et al., 1997).

Carbon dioxide reacts with the carbon in the pyrolized material, producing carbon monoxide gas (Marsh & Rodríguez-Reinoso, 2006; Wigmans, 1989). Water and carbon react to form both carbon dioxide and hydrogen gases (Marsh & Rodríguez-Reinoso, 2006; Wigmans, 1989). Both of these reactions are endothermic, absorbing heat from the surroundings, which requires additional energy input to maintain the required temperatures (Wigmans, 1989). Generally, the reaction products carbon monoxide and hydrogen are burned as supplemental fuel to maintain temperature (Wigmans, 1989).

Chemical activation

The general principle behind the use of activation agents on plant-based feedstocks is the loosening of bonds between cellulose molecules, producing voids (Hagemann et al., 2018; Mohammad-Khah & Ansari, 2009; Wigmans, 1989). Some activation agents depolymerize hemicellulose and lignin in the precursor material (Marsh & Rodríguez-Reinoso, 2006). The activation agent restricts the formation of tar within pores during the carbonization process by occupying the pores of the pyrolized material (Wigmans, 1989). After treatment and heating, the agent can be volatilized or washed away, leading to a revealed microporous structure (Hagemann et al., 2018; Mohammad-Khah & Ansari, 2009; Wigmans, 1989).

Manufacturers most commonly use zinc chloride ($ZnCl_2$), potassium hydroxide (KOH), and phosphoric acid (H_3PO_4) as activation agents (Hagemann et al., 2018). Manufacturers use a ratio of feedstock to agent of 2:1 to 1:3, based on the dry matter of the feedstock (Hagemann et al., 2018). Henning and von Kienle (2021) state that only zinc chloride and phosphoric acid have industrial importance, but other sources suggest that potassium hydroxide and other activation agents are used or researched regularly (Heidarinejad et al., 2020; Marsh & Rodríguez-Reinoso, 2006; Wigmans, 1989). However, alkali metal compounds (such as KOH and NaOH) are primarily used to activate feedstocks derived from coal (Heidarinejad et al., 2020), so these are largely outside of the scope of this report. Phosphoric acid and zinc chloride are most commonly used on lignocellulosic (plant-derived) material (Heidarinejad et al., 2020).

Manufacturers can impregnate feedstocks with chemical activation agents before or after pyrolysis/carbonization (Henning & von Kienle, 2021). The zinc chloride and phosphoric acid processes are similar. Heidarinejad et al. (2020) state that zinc chloride is rarely used for AC intended for food applications due to health risks. The process is as follows (Henning & von Kienle, 2021):

1) The agents are commonly applied to wood-based feedstocks before they enter the furnace.
2) The zinc chloride and feedstock mixture is dried and heated to 600-700 °C, and the phosphoric acid-treated feedstock mixture is dried and heated to 400-600 °C.
3) In the case of zinc chloride, the resulting product is then rinsed with water and acid and the zinc salt is recovered for reuse.
4) Phosphoric acid may be recovered following neutralization and precipitation of phosphate salts or by proprietary methods not disclosed in the literature.
5) Both processes may be followed by steam activation.

Regeneration

AC eventually becomes saturated with adsorbed materials and loses efficacy (El Gamal et al., 2018). Typically it is disposed of in landfills, but it can be regenerated in several ways to restore its adsorptive properties, each with advantageous uses and limitations (see Table 6) (El Gamal et al., 2018).

Table 6: AC regeneration methods, processes and their uses and limitations. Information adapted from El Gamal et al., 2018; Shah et al., 2013

Regeneration method	Summarized process	Uses and limitations
Steam	Steam rapidly heats the spent material causing some of the adsorbed materials to volatilize or decompose. Contaminants are typically carbonized and oxidized for disposal.	Effective on hydrophobic organic molecules; less effective on alcohols, aldehydes, and ketones. May only be useful for contaminants with boiling points near that of water.
Thermal	Typically conducted in high-temperature kilns. Contaminants are desorbed from the AC pores and are pyrolized and gasified by reaction with oxidants.	Effective on organic molecules and some hydrocarbons; energy-intensive and expensive, producing large amounts of waste gases and particulates. May lead to mass loss or efficacy loss of AC due to high temperature decomposition.
Chemical	The spent material is subjected to chemical reagents that dissolve the adsorbate. Another separation process then removes the contaminant and chemical.	Useful for specific adsorbates, but efficiency may be limited.
Microwave	Microwaves penetrate the contaminated AC and are transferred into heat energy to initiate thermochemical reactions.	Low energy usage method and leads to efficient recovery of adsorptive capacity; AC must have sufficient microwave absorbing capacity to be regenerated effectively.
Wet oxidation	Spent AC is suspended in heated aqueous media to dissolve contaminants, which are transformed by the media into less toxic forms and oxidized.	Useful for phenol removal; leads to diminished surface area (and thus porosity and adsorptive potential) of the AC.
Electrochemical	AC suspended in electrolyte is exposed to electric fields, which remove polar contaminants for adsorption onto the electrodes.	Useful for organic pollutants, does not require high temperatures, and is efficient; may require pretreatment processes.
Bio-regeneration	Spent AC is treated to microbial colonies, which use contaminants as a source of biological carbon.	Useful for easily desorbed contaminants like phenolic organics; conditions and nutrients must be maintained to sustain microbes. Primarily used in wastewater treatment applications.

Evaluation Question #2: 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)). Discuss whether the petitioned substance is derived from an agricultural source.

Although some literature uses the term "physical activation," the oxidation resulting from activation with steam or carbon dioxide is not strictly a physical process. It is a combination of both physical and chemical processes. Similarly, chemical activation results in both physical and chemical changes to the starting material, including oxidation, the cleaving of chemical bonds between lignocellulosic molecules, acid hydrolysis, and the formation of chemical bridges cross-linking the biopolymers (Marsh & Rodríguez-Reinoso, 2006).

Evaluation of the two varieties of AC (physical or gas activated and chemical activated) using Guidance NOP 5033-1 *Decision Tree for Classification of Materials as Synthetic or Nonsynthetic* (NOP, 2016) is provided below.

Physical activation

1. *Is the substance manufactured, produced, or extracted from a natural source?*

In the case of AC derived from vegetative sources, the answer is yes. Wood, nutshells, and fruit pits are from a natural source, but AC is not extracted from them.

2. *Has the substance undergone a chemical change so that it is chemically or structurally different than how it naturally occurs in the source material?*

Yes; surface oxidation of carbon results from exposure to steam and carbon dioxide when heated in the absence of oxygen. The resulting material is structurally altered as well through the formation of C-C bonds, rearrangement of carbon sheets, and cross-linking of different forms of carbon in the porous structure.

3. *Is the chemical change created by a naturally occurring biological process, such as composting, fermentation, or enzymatic digestion; or by heating or burning biological matter?*

It depends. Pyrolysis and steam treatment of biological matter involve heating and burning so a nonsynthetic result could be reached for strictly steam activated AC. Conversely, the use of carbon dioxide as a gas activating agent alters the chemistry and structure of the material artificially. For example, as stated in *Evaluation Question #1*, activation with carbon dioxide creates reactive oxygen species. These reactive oxygen species play a functional role in the properties of AC. Therefore, using a plain reading of NOP 5033-1, AC that is physically activated with substances other than steam should be classified as synthetic.

Chemical activation

1. *Is the substance manufactured, produced, or extracted from a natural source?*

Yes, AC is produced in part from vegetative material. When including the chemical activators, phosphoric acid and zinc chloride, however, are not manufactured, produced, or extracted from a natural source so we immediately reach a synthetic conclusion.

2. *Has the substance undergone a chemical change so that it is chemically or structurally different than how it naturally occurs in the source material?*

Yes; the addition of synthetic phosphoric acid or zinc chloride fundamentally transforms the plant material through various chemical reactions in which chemical bonds are formed or broken.

3. *Is the chemical change created by a naturally occurring biological process, such as composting, fermentation, or enzymatic digestion; or by heating or burning biological matter?*

No; the chemical change initiated by activation with synthetic phosphoric acid or zinc chloride is not a naturally occurring biological process or a result of heating or burning.

Charcoal is derived from an agricultural source, but any activation process results in a different material that is no longer agricultural.

Evaluation Question #3: If the substance is a synthetic substance, provide a list of nonsynthetic or natural source(s) of the petitioned substance (7 CFR 205.600(b)(1)).

The nature of activation is that it chemically changes the substance, transforming it into a synthetic material. Without some form of activation, the material is just charcoal which does not have sufficient adsorptive capacity for commercial applications (Marsh & Rodríguez-Reinoso, 2006). Since AC was included on the National List in 2006, it has been considered a synthetic material whether activated by physical or chemical means.

Historically, wood or bone charcoal (i.e., non-activated biochar) has been used in the refining of alcoholic spirits and sugar but the use of activated carbons for direct addition or filtration has almost completely replaced these practices (Bansal & Goyal, 2005). In the research for this report, we only located literature describing the use of biochar as a filter medium for large-scale wastewater treatment, groundwater remediation efforts, and heavy metal reduction in contaminated drinking water.

Evaluation Question #4: Specify whether the petitioned substance is categorized as generally recognized as safe (GRAS) when used according to FDA's good manufacturing practices (7 CFR 205.600(b)(5)). If not categorized as GRAS, describe the regulatory status.

AC is categorized as GRAS when used as a filter aid in certain applications (Federation of American Societies for Experimental Biology, 1981); however this determination is not published within FDA regulations (21 CFR). Not all GRAS determinations are published, such as certain "prior sanctioned" food substances (Center for Food Safety and Applied Nutrition, 2018), as well as "self-determined" or independent conclusions of GRAS status.

See *Approved Legal Uses of the Substance* for the specific GRAS uses that authors have noted in publicly-available literature, as well as discussion of the transparency (or lack thereof) of GRAS status at the current time.

Evaluation Question #5: Describe whether the primary technical function or purpose of the petitioned substance is a preservative. If so, provide a detailed description of its mechanism as a preservative (7 CFR 205.600(b)(4)).

The primary technical function of AC in food processing is that of a filtering aid. Food processors use AC to remove impurities that affect the taste, color, turbidity, and/or odor of food (Bernal et al., 2016; Federation of American Societies for Experimental Biology, 1981; Henning & von Kienle, 2021). Thus, its primary technical function or purpose is not that of a preservative. However, the act of filtration may indirectly affect preservation, depending on the food and the impurities filtered.

The definition of chemical preservative at 21 CFR 101.22(a)(5) is: "any chemical that, when added to food, tends to prevent or retard deterioration thereof, but does not include common salt, sugars, vinegars, spices, or oils extracted from spices, substances added to food by direct exposure thereof to wood smoke, or chemicals applied for their insecticidal or herbicidal properties." Filtering with AC can remove certain compounds from food that are associated with that food's deterioration. For example, melanoidins and other dark colored compounds form as part of what is known as the Maillard reaction. The Maillard reaction is a network of natural, non-enzymatic reactions that occur when food is heated, and for some foods, occurs under storage conditions at or below room temperature (Ames, 1990). While the Maillard reaction and the melanoidins it produces can yield desirable characteristics in some food processing applications such coffee roasting and bread baking (Wang et al., 2011), the browning and taste alteration resulting from the products of the Maillard reaction is undesirable in some foods (Ames, 1990). Arslanoğlu et al. (2005) found AC to be effective at removing these melanoidins and other dark colored compounds from peach puree in order to preserve its color, aroma, and taste.

Another example of AC's adjacent role in food preservation is its removal of fumaric acid from apple juice (Tulek & Yilmaz, 2006). The microorganism, *Rhizopus stolonifera*, produces fumaric acid in apples and apple juice during processing and storage, resulting in lower quality apple juice. Its presence can be an indicator of microbial degradation of the fruit (Tulek & Yilmaz, 2006). Since compounds such as fumaric acid and melanoidins are involved in the degradation of certain foods, one could consider their removal via AC filtration as playing a role in the preservation of those foods.

The term preservative more commonly refers to antimicrobial substances that prevent food decay through action against spoilage-inducing microorganisms. The National Academies (1973) describes preservatives as "substances added to foods to prevent or inhibit microbial growth." Lakshmi et al. (2018) studied filtration using AC from different biomass sources and its efficacy against a suite of pathogenic microorganisms. In their review, the authors reported that AC showed good potential as an antimicrobial treatment in food processing applications (Lakshmi et al., 2018). This appears to be an emerging or potential area of use only. AC filtration more commonly targets the removal of chemical contaminants. Several reports have described the modification of AC by coating it with quaternary ammonium (Karnib et al., 2013) or silver (Altintig et al., 2023) to enhance its efficacy as an antimicrobial agent, mainly for use in water purification. However, the literature reviewed for this report did not indicate that food processors employ AC filtration for the purpose of food preservation in the traditional sense of microbial inhibition.

Evaluation Question #6: Describe whether the petitioned substance will be used primarily to recreate or improve flavors, colors, textures, or nutritive values lost in processing (except when required by law) and how the substance recreates or improves any of these food/feed characteristics (7 CFR 205.600(b)(4)).

As a filtering aid, AC is not used to recreate flavors, colors, or nutritive values lost in processing. However, AC removes compounds that can affect color and flavor of food and beverages. As noted in *Evaluation Question #5*, manufacturers can use AC as a filter aid to remove dark colored compounds from foods such as peach puree (Arslanoğlu et al., 2005) and beet molasses (Bernal et al., 2016).

AC is also used as a clarifying agent. Al-Farsi (2003) tested various methods for clarifying date juice from low-quality dates to obtain a syrup of acceptable quality. He found that granular AC removed the most color from the date juice (Al-Farsi, 2003). Powdered AC did not remove as much color from the date juice as granular AC, due to the carbon remaining in the solution (filtration did not eliminate the powdered AC from the clarified juice) (Al-Farsi, 2003). Tulek and Yilmaz (2006) found that treatment of apple juice with AC (granular or powdered form not specified) at the highest dosage level (10 g/L) actually decreased color quality. However, AC treatment combined with gelatin and bentonite filtration yielded the best color for apple juice among eight different treatments in their study (Tulek & Yilmaz, 2006). Wine makers also use AC to decolorize wine (Subden et al., 1986).

Besides color, flavor and odor are other important characteristics that food processors seek to modify using AC. In wine, AC removes some organic molecules and, to a lesser extent, cations and transition metals associated with unfavorable flavors and odors (Subden et al., 1986). However, wine makers have to be careful in the use of AC, since some applications could result in the removal of desirable flavors (Subden et al., 1986).

Phenolic compounds affect various properties in foods, including color and flavor. Depending on the food and the specific phenolic compounds present, a food processor may wish to preserve or remove them. Seo and Morr (1985) investigated whether AC was suitable for removing phenolic compounds that contribute to off flavors and color deterioration in peanut flour. They found that treating peanut flour with AC removed 82% of total phenolic acids, primarily *p*-coumaric acid (Seo & Morr, 1985). Similarly, AC effectively removed *p*-coumaric acid from soy protein extract, along with syringic and ferulic acids, thereby improving the extract's odor and flavor profile (How & Morr, 1982).

Regarding impacts on nutritive value, we found no information to indicate that food processors use AC to directly recreate or improve the nutritive values of food. As a filter aid, AC functions as a mechanism for removing substances through adsorption. Nevertheless, AC filtration may indirectly affect the nutrient content of food. *Evaluation Question #7* further examines the impact of AC filtration on nutritional quality.

Evaluation Question #7: Describe any effect or potential effect on the nutritional quality of the food or feed when the petitioned substance is used (7 CFR 205.600(b)(3)).

As with color, flavor, and odor, the impact of AC filtration on the nutritive quality of food largely depends on the food, the specific AC utilized, and the compounds targeted for removal. The formation of browning compounds, melanoidins, during the Maillard reaction can result in the loss of nutritive value (Arslanoğlu et al., 2005) due to the break down or inactivation of amino acids in proteins (Martins et al., 2000). It can also affect food quality and safety through the inhibition of certain enzymes and through interactions with metal ions (Martins et al., 2000). Thus, using AC to remove these browning compounds can help maintain the nutritive value of the food.

In some applications, AC can retain beneficial phenolic compounds, such as those that are valued as antioxidants. Çoklar and Akbulut (2010) found that using AC to clarify apple juice preserved the juice's phenolic compounds and their associated beneficial properties. A study by Soto et al. (2008) sought to recover antioxidant phenolic compounds from distilled grape pomace using adsorption with AC, followed by desorption.

In other applications, AC may remove both undesirable compounds and beneficial nutritive compounds from food. In one study, researchers carried out proteolytic enzyme hydrolysis of casein, a protein in milk, to make it more digestible (Cogan et al., 1981). The protein developed a bitter taste through the hydrolysis process. The researchers therefore treated it with AC, which removed the bitter taste, but also removed several essential amino acids: tryptophan, phenylalanine, and arginine, thus lowering the nutritional quality of the hydrolyzed protein. As a result, the researchers supplemented the milk with the removed amino acids so that it would meet nutritional quality requirements (Cogan et al., 1981). This study took place in 1981. Modern preparation techniques for AC enable processors to modify and adapt the absorptive capacity and specificity of AC for specific applications, to more precisely target the contaminants intended for removal (Bansal & Goyal, 2005). The effects of AC treatment can therefore differ substantially based on how the AC is produced and activated (Bansal & Goyal, 2005).

We did not find current literature to suggest that adverse effects on the nutritional value of food is a notable concern with AC filtration.

Evaluation Question #8: List any reported residues of heavy metals or other contaminants in excess of FDA tolerances that are present or have been reported in the petitioned substance (7 CFR 205.600(b)(5)).

AC is itself used to remove contamination, including organic compounds and heavy metals (see *Specific Uses of the Substance*, *Approved Legal Uses of the Substance*, *Evaluation Question #1* and *Evaluation Question #3*). Therefore, AC is likely to become contaminated with numerous heavy metals and other substances with use.

The FDA establishes "action levels" for poisonous or deleterious substances that are unavoidable in human food and animal feed (U.S. FDA, 2000). These include aflatoxin, cadmium, lead, polychlorinated biphenyls (PCBs), and many other substances. The FDA uses different action level tolerances for these substances, depending on the commodity. Commodities are largely food items; however, the FDA also includes tolerances for ceramic items, such as eating vessels and utensils. AC is not included in their list of commodities (U.S. FDA, 2000).

The online version of the Food Chemicals Codex specifies that AC should not contain more than 10 mg/kg of lead nor more than 3 mg/kg of arsenic (United States Pharmacopeial Convention, 2016). The Food Chemicals Codex does not provide specific limit values for other heavy metals or contaminants; however, it does note that AC should pass a test for cyanogen compounds and higher aromatic hydrocarbons (United States Pharmacopeial Convention, 2016).

Evaluation Question #9: Discuss and summarize findings on whether the manufacture and use of the petitioned substance may be harmful to the environment or biodiversity (7 U.S.C. 6517(c)(1)(A)(i) and 7 U.S.C. 6517(c)(2)(A)(i)).

The manufacture and use of AC can have beneficial and adverse environmental impacts, and these vary depending on the stage of the AC life cycle, from raw material extraction to production, use, and disposal.

According to a market study, the global use of AC in 2022 was around 3 million tons (Global Industry Analysts, Inc., 2022). The authors project that use will grow to 3.9 million tons by the year 2026. Around 471,000 tons are used in the United States (Global Industry Analysts, Inc., 2022). However, much of this AC is used in purifying air from coal plants and purifying industrial chemicals (Global Industry Analysts, Inc., 2022). We did not find information indicating the amount used in organic production.

Agrowastes are a global ecological problem because their disposal can produce water contamination, or air pollution when burned openly (Jha et al., 2021). Residual biomass from various industries (such as wood chips and coconut shells) also create large volumes of waste going to landfills (Kim et al., 2018; Vilén et al., 2022). The conversion of these lignocellulosic materials into AC (a useful, valuable adsorbent) could help address the environmental problems associated with these waste streams (Das et al., 2023; Jha et al., 2021).

Aside from the benefits of diverting biomass from waste streams, the environmental impact associated with AC manufacturing varies depending on the carbonaceous materials used as feedstock (Kim et al., 2018) and the method of activation (physical or chemical) (Kim et al., 2018). We focused specifically on the environmental impacts of biomass for AC production sourced from coconut shells and wood. These materials appear to be the two most commonly used worldwide, and the raw materials that have been most researched in the context of industrial Life Cycle Assessments (LCA) (Arena et al., 2016; Gu et al., 2018; Kim et al., 2018; Vilén, 2021; Vilén et al., 2022).

Stages in the life cycle of AC that have the most impact on the environment are carbonization, activation, and where applicable, reactivation (Kim et al., 2018; Vilén, 2021).

Carbonization of AC

The environmental impact of carbonizing coconut shells varies depending on where and how it is carried out: within an industrial facility (Arena et al., 2016; Kajina et al., 2019; Vilén, 2021; Vilén et al., 2022) or in an open pit (common practice by coconut charcoalers in South-East Asia) followed by transportation to an AC production facility for activation (Vilén, 2021). Carbonization of coconut shells in an open pit releases all the waste products into the atmosphere or the ground, whereas carbonization in a closed pit offers some abatement of the emissions (Vilén, 2021). The open-pit carbonization method for coconut AC significantly increases the environmental impacts, especially toxicity, over that of the closed-pit method (Vilén et al., 2022). Industrial carbonization and activation (utilizing kilns and furnaces) is more environmentally friendly than open pit carbonization (Vilén, 2021). Emissions from furnaces are usually cleaned in an afterburner or scrubber before release into the atmosphere (Chowdhury, 2013).

Activation of AC

As mentioned in *Evaluation Question #1*, activation can be performed through physical and chemical means. Chemical activating agents have several drawbacks. They can be toxic to the environment, corrosive, and AC manufacturers may need to use additional chemicals to wash the activating agent off (Varila et al., 2017). Hjaila et al. (2013) and Yahya et al. (2015) suggested recovering and reusing chemical agents to reduce their environmental impact (Vilén, 2021). However, recovery is not a standard procedure and may not be possible depending on the activating agent and washing chemical used (Vilén, 2021).

Physically activated AC has lower Global Warming Potential (GWP) than the chemically activated counterpart (Vilén, 2021).

Global Warming Potential (GWP)

Direct CO_2 emissions largely contribute to the GWP of AC production (Vilén, 2021). The calculations performed by Vilén (2021) indicate that when considering carbon emissions, bark has a GWP of 9.2 CO2-eq/kg granular AC, which is very close to that of coal AC (9.5 CO2-eq/kg granular AC). Coconut granular AC GWP is lower than bark and coal granular AC at 7.6 CO2-eq/kg granular AC, while reactivated granular AC (from coal) has the smallest GWP, at 2.1 CO2-eq/kg granular AC.

Producing electricity to support the manufacturing of all types of granular AC generates toxic emissions (particularly beryllium), adding to AC's human toxicity potential and aquatic ecotoxicity potential (Vilén et al., 2022).

Overall, the most environmental friendly granular AC appears to be reactivated biomass granular AC. However, it is uncertain whether coconut and bark granular ACs are feasible to reactivate and may not be (Vilén, 2021).

End of Life of the AC

Sixty-six percent of nonhazardous granular AC goes to reactivation, 7 percent is disposed of by incineration or thermal destruction at cement kilns, and 27 percent is disposed in landfills (National Research Council, 2009). Sweetener manufacturers like Cargill and Archer Daniels Midland Company, for example, reactivate 40 percent of the granular AC they use on site (National Research Council, 2009).

When reactivation is not a possible path, waste incineration may be used to produce heat or as a replacement for a conventional fuel in another industry (Joseph et al., 2020). Operators mix spent AC with other wastes before incineration at a municipal waste incinerator. While this is a beneficial re-use of the material, incineration also causes emissions of gases that include: hydrogen chloride, nitrogen oxides, carbon monoxide, dioxins - polychlorinated dibenzo-*p*-dioxins and furans - polychlorinated dibenzofurans (Silva et al., 2019). The ashes produced from the incineration process can be disposed by landfill or sometimes used in construction applications and in the manufacturing of new materials (Silva et al., 2019). Ashes may contain high amounts of hazardous constituents, which may leach out when exposed to rainwater and can contaminate soil, water bodies, groundwater systems, and, subsequently, fauna and flora (Silva et al., 2019).

Similarly, problems arising from the disposal of AC in the landfill may be (Shah et al., 2013):

- release of adsorbed pollutants into the environment
- biological growth and
- fire hazards

The world demand for virgin AC is quickly expanding and likely leading to an increase in available spent AC. Thus, reusing AC via reactivation or other means would be beneficial for the environment (Shah et al., 2013).

Evaluation Question #10: 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)).

The use of AC as a filtering aid can have positive effects on human health because it can remove toxic substances such as insecticides, herbicides, chlorinated hydrocarbons, heavy metal ions, and phenols, typically present in many water supplies (Mohammad-Khah & Ansari, 2009).

The AC lethal dose (LD_{50} value) when administered to rats is <2000 mg/kg (Roth, 2016). When consumed, AC is not toxic to humans (ECHA, 2023; Olson, 2010; Roth, 2016) and it is used by medical professionals to absorb toxins in cases of human poisoning (Alkhatib & Zailaey, 2015; Olson, 2010; Silberman et al., 2023). Intake of AC after consumption of most drugs and poisons appears to prevent systemic absorption when given within 1-2 h of ingestion (Olson, 2010). The only risks associated with AC consumption are the pulmonary aspiration of gastric contents when it is administered to overdosed patients that might not be entirely conscious (Olson, 2010) and bowel obstructions (Silberman et al., 2023). Although many patients vomit after the administration of AC, only a few of them aspirate gastric contents into the lungs causing a pneumonitis (Olson, 2010).

When consumed by humans (one gram 30 min before the meal and one gram shortly after the meal), AC can contribute to reducing excessive flatulence after eating due to its efficiency adsorbing gases (Sadler, 2018). Purveyors of dietary supplements sell ACs as a dietary supplement that detoxifies the gastrointestinal tract. Some empirical studies have demonstrated that supplementing animal food with AC can bind toxic substances, control pathogens, and reduce methane production (Toth & Dou, 2016). However, we did not find detailed and recent studies that measured the benefits of AC when used as a dietary supplement in the human diet.

Evaluation Question #11: Describe any alternative practices that would make the use of the petitioned substance unnecessary (7 U.S.C. 6518(m)(6)).

We found no studies that directly identified and compared alternative practices to AC as a filtering aid in food processing.

Fining agents are materials added to wine to remove undesirable components and are not expected to remain in the final product (Waterhouse et al., 2016). Industry-wide progress in wine making means sensory correction of these products using fining agents like AC is less necessary than in the past (Ribéreau-Gayon et al., 2006a). For example, Boselli et al. (2010) demonstrated the experimental application of nitrogen blanketing throughout the vacuum-pressing of the grape juice reduced the degradation of phenolic compounds. This resulted in a decreased browned phenolic effect by 87% in Chardonnay and 10%

in Greschetto grapes. Despite this, there is still considerable interest in the treatment of phenolic off-odor and color by fining agents (Australian Wine Research Institute, 2021; Lisanti et al., 2017; Pryadikhina et al., 2021).

Wine aroma is often linked to varietal and climate factors (Boselli et al., 2010; Lisanti et al., 2014). Incidentally, the sensory quality of wine grapes can also succumb unpredictably to the influence of climate change. Examples of this include off-odors from smoke (Kelly et al., 2014). We found no data suggesting alternative practices to address these type of off-odors.

We found no data related to alternative practices to the use of AC as an adsorbent in sugar refining. In a review of adsorption technology in the sugar industry, Iwuozor et al. (2023) likewise identified the lack of direct comparison of adsorbents and processes as a substantial challenge for the industry. Hamachi et al. (2003) suggested ultrafiltration as a means to decolorize cane sugar, but ultimately concluded that the use of an absorbent (e.g., AC) was still necessary to obtain complete decolorization.

Evaluation Question #12: 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)).

We found no data suggesting that any materials were a direct substitute for AC as a filtering aid for the same range of processed food and beverage products (see **Table 3**). However, winemakers and manufacturers of plant oils may be able to use bentonite as an alternative to AC in some instances.

Bentonite

AC is a non-selective filtering aid that can remove color and undesirable odors and flavors (Australian Wine Research Institute, 2023). As a fining agent, bentonite is not as effective at color removal as AC, but it is more effective for tannin removal, clarity, and stability (Australian Wine Research Institute, 2023). Winemakers commonly apply bentonite to remove turbidity (cloudiness) due to proteins in white wine. In contrast, winemakers use AC to improve different qualities related to color and odor (Ribéreau-Gayon et al., 2006b).

There is limited evidence that bentonite is suitable to correct color appearance in juice. Youn et al. (2004) demonstrated that bentonite was a more effective filter-aid pretreatment than AC for the clarifying of reconstituted apple juice, as the resulting modifications produced a more acceptable color.

Bentonite is commercially available both domestically and globally (Future Market Insights, 2023), however its use has drawbacks. Inhalation of bentonite dust presents health risks to winemakers (Sommer & Tondini, 2021). Bentonite disposal is a challenge to wine producers because it requires professional disposal (Butzke, 2010; Sommer & Tondini, 2021). Additionally, there is no way to reuse it (Butzke, 2010; Waterhouse et al., 2016). Inadequate disposal practices can result in the accumulation of expired bentonite in winery wastewater ponds and consequently can lead to increased algal growth within the ponds (Butzke, 2010). Fernández-Calviño et al. (2015) demonstrated application of bentonite waste in excess of 20 Mg ha^{-1} can also result in an excessive increase to soil pH and copper accumulation. Bentonite is a mined mineral and therefore acquiring it causes land surface disturbances. Individual bentonite mines are shallow and a few hectares in size, but extraction moves along the clay deposit. The cumulative effect of these mining activities can lead to significant disturbances for rangeland ecosystems (Pratt & Beck, 2019). For example, Pratt and Beck (2019) demonstrated that the sage grouse is a species sensitive to these disturbances. The effects of bentonite mining include reduced survival of brooding animals, limited to when mines are active, and long-term habitat loss that is slow to recover even with restoration efforts.

Evaluation Question #13: Provide a list of organic agricultural products that could be alternatives for the petitioned substance (7 CFR 205.600(b)(1)).

We found no data suggesting that any materials are a direct substitute for AC as a filtering aid for the same range of processed food and beverage products (see **Table 3**). However, casein is one material that has commercially demonstrated limited capacity as an alternative to AC in the wine industry.

Casein

Casein is a multipurpose material for wine producers. Casein can clarify wines, but it can also improve color and odor (Ribéreau-Gayon et al., 2006b). However, it is not as effective as AC for decolorizing wine (Australian Wine Research Institute, 2023). We found no data suggesting casein is a suitable alternative to AC for the production of any of the other processed foods referenced in **Table 3**.

Organic casein is currently available (USDA, 2023). Non-organic casein is commercially available both domestically and globally (Future Market Insights, 2022).

There is increasing regulation of casein by governments worldwide because of the potential allergenic risk or food intolerance (Vassilopoulou et al., 2011). However, there is building evidence that a clinical reaction to wines fined with these materials is highly improbable (Deckwart et al., 2014; Restani et al., 2012). Casein powder is available in organic form (USDA, 2023). This is an animal-derived material, and as such is subject to rising scrutiny in recent years from consumers concerned with food preference, sustainability, and animal cruelty issues (Ramezani et al., 2020; Shirvani et al., 2023).

Report Authorship

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