Sodium Bicarbonate

Handling/Processing

Identification

Chemical Names:
sodium hydrogen carbonate; monosodium hydrogen carbonate; carbonic acid, monosodium salt; $NaHCO_3$

Other Name:
baking soda; bicarbonate of soda; nahcolite; natrii hydrogenocarbonas; sodium acid carbonate

Trade Names:
Effer-Soda; Sal de Vichy

CAS Numbers:
carbonic acid monosodium salt: 144-55-8

Other Codes:
E Number 500 (sodium carbonates)
EC Number 205-633-8
UNII 8MDF5V39QO

Summary

This full scope technical report provides information to the National Organic Standards Board (NOSB) to support the sunset review of sodium bicarbonate [currently listed at 7 CFR 205.605(a)(26)]. This report focuses on the uses of sodium bicarbonate in organic processing and handling, as a nonagricultural (nonorganic) substance allowed as an ingredient in or on processed products labeled as "organic" or "made with organic (specified ingredients or food group(s))."

In 2020, the NOSB noted that certifiers raised a classification question for sodium bicarbonate. Certifiers asked for clarification on what manufacturing processes were to be considered nonsynthetic and allowed under the listing at § 205.605(a) (NOSB, 2020). This report provides technical information to support discussions about manufacturing processes and classification (in particular, *Evaluation Questions #1(B)* and *#1(C)*). Because of the NOSB's interest in possibly reclassifying the substance made from Trona ore as synthetic, this report offers considerable analysis of those manufacturing process steps.

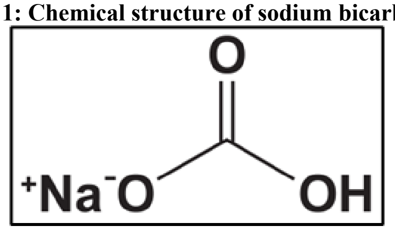
A Technical Advisory Panel (TAP) report on sodium bicarbonate was considered by the NOSB in 1995 (NOSB, 1995). No technical report has been written for the NOSB on this material since the 1995 TAP report. Sodium bicarbonate was included on the National List of Allowed and Prohibited Substances (hereafter referred to as the "National List") with the first publication of the National Organic Program (NOP) Final Rule (65 FR 80548, December 21, 2000). The NOSB has continued to recommend its renewal in 2005, 2010, 2015, and 2020 (NOP, 2010; NOSB, 2009, 2015, 2020).

Sodium bicarbonate is primarily used as a component of baking powder and, since it is listed at § 205.605(a), only nonsynthetic forms are allowed.

Characterization

Composition of the Substance:
Sodium bicarbonate is a salt comprised of a sodium ion (Na^+) and a hydrogen carbonate ion (HCO_3^-) (see Figure 1, below) (National Center for Biotechnology Information, 2024). It consists of 57.13% oxygen, 27.37% sodium, 14.30% carbon, and 1.20% hydrogen. The term "bicarbonate" describes twice as much carbonate produced per sodium relative to sodium carbonate and other carbonate salts, but this is outdated chemical nomenclature (Alfa Chemistry, 2024). The current chemical naming convention assigns the term "hydrogen carbonate." However, the food industry primarily still uses the older outdated nomenclature.

Figure 1: Chemical structure of sodium bicarbonate.



Source or Origin of the Substance:

Food-grade sodium *bicarbonate* is primarily derived from the carbonation of a refined sodium *carbonate* precursor.[1] The sodium carbonate precursor can be obtained from a naturally occurring mineral source (sesquicarbonate or nahcolite extraction) or from the Solvay process (a chemical synthesis reaction producing sodium carbonate from sodium chloride, ammonia, and calcium carbonate) (Eggeman, 2001; Rahimpour et al., 2024; Thieme, 2000).

Mineral precursor sources

Sodium bicarbonate ($NaHCO_3$) occurs in several naturally occurring minerals (Eggeman, 2001). However, the only sources of commercial interest are the following minerals:

- sodium sesquicarbonate (a mixture of sodium carbonate and sodium bicarbonate, $Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$), also called trona
- nahcolite, a form of relatively pure sodium bicarbonate ($NaHCO_3$)

Naturally sourced sodium bicarbonate is usually derived from sodium carbonate extracted from trona. Less often, sodium bicarbonate is obtained from the solution mining of nahcolite deposits. These processes are described in further detail in *Evaluation Question #1(B)*.

Solvay process precursor source

Sodium bicarbonate can also be produced through a chemical synthesis process known as the ammonia-soda process, more commonly known as the Solvay process. The ammonia-soda process produces sodium carbonate rather than sodium bicarbonate (Eggeman, 2001; Thieme, 2000). As described by Eggeman (2001) and Thieme (2000), sodium chloride reacts with ammonia and carbon dioxide through a multi-step reaction. Sodium bicarbonate serves as an intermediary before sodium carbonate is obtained through a final calcination step. In this step, sodium bicarbonate is heated, producing water vapor, carbon dioxide, and sodium carbonate. This process and its steps are thoroughly detailed in *Evaluation Question #1(B)*. The final sodium carbonate can be carbonated to regenerate refined sodium bicarbonate, which contains less impurities. Sodium carbonate and bicarbonate produced through the Solvay process are synthetic substances currently not allowed on the National List.

Properties of the Substance:

Sodium bicarbonate appears as a white, crystalline solid that is commercially available in different particle sizes ranging from a fine powder to uniform granules (see Table 1, below) (Rowe et al., 2009). The average particle size diameter of the powder form may range between 15-300 µm (Organisation for Economic Co-operation and Development (OECD), 2002). Bakers using sodium bicarbonate for chemical leavening typically use powders with an average particle size diameter of 70-90 µm (Gélinas, 2022). Sodium bicarbonate is stable in dry air, but decomposes with humidity:

- Below 48% relative humidity (RH), sodium bicarbonate is stable at 40 °C (Kuu et al., 1998).
- Below 76% RH, it is stable at 25 °C (Kuu et al., 1998).
- Below 80% RH, the moisture content of sodium bicarbonate is less than 1% w/w (Rowe et al., 2009).[2]
- Above 85% RH, sodium bicarbonate absorbs excessive amounts of water and may start to decompose as carbon dioxide molecules form (Rowe et al., 2009).
- Aqueous solutions of sodium bicarbonate will decompose, with partial conversion into sodium carbonate at ambient temperatures (Rowe et al., 2009).

Sodium bicarbonate is odorless, but will absorb odors from its surroundings (Thieme, 2000). For these reasons, storage in dry, airtight conditions is recommended.

Sodium bicarbonate is highly soluble in water, but it is insoluble in ethanol. Solubility is also lower in the presence of sodium carbonate (National Center for Biotechnology Information, 2024). The alkalinity of sodium bicarbonate increases in solution as it stands, or when agitated or heated (United States Pharmacopeial Convention, 2008).

Solid, non-dissolved sodium bicarbonate begins decomposing when heated over 50 °C with complete decomposition at 270 °C (National Center for Biotechnology Information, 2024). It releases acrid smoke, fumes, and carbon dioxide around 50 °C. When heated to decomposition, the fumes are toxic and composed of carbon monoxide, carbon dioxide, and sodium oxides (National Center for Biotechnology Information, 2024). In an aqueous solution,

[1] Carbonation is the process by which carbon dioxide is dispersed into a solution (Sih et al., 1979); in the context of this technical report, a sodium carbonate and/or sodium bicarbonate solution is used. Carbon dioxide reacts with sodium carbonate, producing sodium bicarbonate, which precipitates out of the solution.

[2] The abbreviation (w/w) indicates weight for weight. The unit expressed here is weight-percent concentration and denotes the relative mass of sodium bicarbonate (or solute) dissolved in a measured mass of liquid (solution).

sodium bicarbonate begins to break up into carbon dioxide and sodium carbonate at about 20 °C and decomposes completely when boiled (National Center for Biotechnology Information, 2024; Rowe et al., 2009).

Weak acids (e.g. citric and tartaric acid) easily decompose sodium bicarbonate (National Center for Biotechnology Information, 2024; Rowe et al., 2009).

Table 1: Physical and chemical properties of sodium bicarbonate (Alfa Chemistry, 2024; Mallinckrodt Inc., 2024; National Center for Biotechnology Information, 2024; Organisation for Economic Co-operation and Development (OECD), 2002; Rowe et al., 2009).

Property	Value
Physical state and appearance	Solid, fine powder (15-300 µm), or granules
Odor	Odorless
Taste	Saline, slightly alkaline
Color	White
Molecular weight	84.01 g/mol
Specific gravity	2.16-2.22 g/cm3
pH	8.3 (freshly prepared 0.1 mol/L solution at 25 °C)
Solubility	Soluble in 10 parts water at 25 °C; insoluble in alcohol
pKa	6.3
Boiling point	851 °C
Melting point	270 °C (with decomposition)
Critical temperature	50 °C
Vapor pressure	2.58×10^{-5} mmHg at 25 °C
Stability	Stable below 76% relative humidity at 25 °C; begins to dissociate at 50 °C
Reactivity	Reacts with acids, acidic salts, and many alkaloidal salts, with the evolution of carbon dioxide

Specific Uses of the Substance:

Sodium bicarbonate's food processing and handling uses are varied (see Table 2, below). It is primarily used in meat products, baked goods, baking mixes, cocoa processing, and as a surface cleaner.

Table 2: Specific uses of sodium bicarbonate in the processing and handling of foods.

Use	Type of food products	Reference(s)
pH control agent	Meat products: beef, chicken, pork; cocoa beans and liquors; tomato concentrates	(Åsli & Mørkøre, 2012; Chen et al., 2024; PubChem, 2024; Rodríguez et al., 2009; United States Pharmacopeial Convention, 2008)
Leavening agent	Baked goods, baking powder	(Miller, 2016; United States Pharmacopeial Convention, 2008)
Texturizer	Meat products: beef, chicken, pork; baked goods	(Chen et al., 2024; De Leyn, 2014)
Surface cleaner	N/A	(Bonfim-Rocha et al., 2019; Olson et al., 1994)
Food additive	Meat products—as a water retention agent; seafood products—as lipid preservative and texturizing agent	(Åsli & Mørkøre, 2012; Bonfim-Rocha et al., 2019; Chen et al., 2024; Wu et al., 2023)

pH control agent

Sodium bicarbonate is an alkaline compound that is added to foods to prevent deterioration by neutralizing the acidic content. This practice is common in meat products (Åsli & Mørkøre, 2012). Lactic acid buildup and a subsequent lowered pH occur over time in meat products and are a sign of deterioration. Manufacturers of marinade products use sodium bicarbonate as an alternative to phosphates, normally used to increase pH (Åsli & Mørkøre, 2012; Chen et al., 2024).

Sodium bicarbonate is also used in the cocoa industry for the alkalization process (Moser, 2015; Rodríguez et al., 2009). The alkalization process was first developed in 1828 by the Dutch chemist Coenraad Van Houten, who produced what is known as "Dutched" cocoa, or alkalized cocoa. The alkalization process, or Dutch process, lowers the bitterness, increases the pH, and darkens the color of cocoa powder (Moser, 2015; Rodríguez et al., 2009).

The alkalization process can occur at different points in the cocoa bean processing stages (Moser, 2015; Rodríguez et al., 2009). The main methods of alkalization with sodium bicarbonate are (Moser, 2015):

- nib alkalization
- cocoa cake alkalization
- chocolate liquor alkalization

Cocoa processors conduct nib alkalization, the most prevalent cocoa alkalization process in the United States and Europe, after cleaning but before roasting (Moser, 2015). Nib alkalization involves soaking the deshelled cocoa nibs in an up to 50% alkali solution. The nibs are aired out and sometimes steamed before roasting.

The cocoa cake alkalization and chocolate liquor alkalization processes occur after nibs are roasted (Moser, 2015). In cocoa cake alkalization, the roasted nibs are ground and pressed into a cake. Gravel-sized pieces of cocoa grounds from the press cake are treated with an alkali solution under pressure and vacuum (Moser, 2015). The alkalized cake is then dried and milled to the final product.

Cocoa processors choose either chocolate liquor alkalization or cake alkalization. The processes are similar; however, chocolate liquor alkalization requires less equipment and a water removal step (Moser, 2015). Roasted nibs are liquor milled, then treated with an alkali solution. Processors further treat the viscous liquid (*i.e.,* evaporation, further grinding) to a final product.

Though the primary use of sodium bicarbonate in baked goods is as a leavening agent, food manufacturers may use excess amounts of sodium bicarbonate to produce certain flavors and darker colors (Miller, 2016). Manufacturers increase the pH of the baked goods when they add more sodium bicarbonate than what is needed for leavening. These effects may be desired in products such as chocolate cakes or muffins (Miller, 2016).

<u>Leavening agent</u>

Sodium bicarbonate is a leavening agent commonly used in baked goods (Miller, 2016). It can be used as a single leavening agent in some cookies and snack crackers because it slightly decomposes during heating, releasing carbon dioxide. For products that require higher carbon dioxide gas levels, such as cakes and other batter-based products, sodium bicarbonate must be combined with one or more leavening acids (Miller, 2016). Sodium bicarbonate works as a base that reacts with leavening acids, producing carbon dioxide gas (Miller, 2016).

Sodium bicarbonate is the most popular gas-releasing leavener after baker's yeast because of its low cost, ease of handling, low toxicity, high purity, and lack of taste contribution when used in low amounts (Gélinas, 2022). Performance generally depends on the exact recipe used, as interactions between sugar, fat, and moisture may affect the rising effect of leavening agents.

<u>Texturizer</u>

Sodium bicarbonate has a texturizing effect due to its leavening properties and water retention capabilities. Baked products that would otherwise have a hard texture can become softer by using more leavener (De Leyn, 2014). Some meat products retain more water and juiciness when treated with sodium bicarbonate (see Table 2, above) (Åsli & Mørkøre, 2012).

<u>Surface cleaner</u>

Sodium bicarbonate is commonly used as a general-purpose cleaner, often in combination with vinegar (Olson et al., 1994).

<u>Other uses</u>

Sodium bicarbonate has a wide range of non-food uses, including as an ingredient in (Bonfim-Rocha et al., 2019):

- exhaust flue gas acid neutralizers
- fire extinguisher powders
- paper sizing products
- animal feeds
- soft water treatments
- plastic foams

Sodium bicarbonate also has a wide range of uses in medicine including, but not limited to: electrolyte replenisher, active ingredient in toothpaste, and antacid (PubChem, 2024).

<u>Approved Legal Uses of the Substance:</u>

Food manufacturers use sodium bicarbonate as a food ingredient and processing aid. Therefore, the relevant legal uses of this substance are regulated by the FDA (US FDA, 2023). Sodium bicarbonate is Generally Recognized as Safe (GRAS) without limitations other than current good manufacturing practice (21 CFR 582.1736). The FDA notes its use as a general purpose food additive (see below).

The FDA also lists sodium bicarbonate as an ingredient or processing aid in the production of other products, such as:

- self-rising white corn meal (§ 137.270)
- self-rising flour (§ 137.180)
- cacao nibs (§ 163.110)
- breakfast cocoa (§ 163.112)
- chocolate liquor (§ 163.111)
- cocoa butter substitute (§ 184.1259)
- tomato concentrates (§ 155.191)

The FDA also lists sodium bicarbonate as an ingredient in a sanitizing solution [§ 178.1010(b)(41)]. This sanitizing solution is composed of many ingredients, including some that are not allowed to contact organic products such as ammonium chloride and methylene blue.

Standard of identity for sodium bicarbonate, under FDA

The FDA describes the standard of identity for sodium bicarbonate as follows (§ 184.1736):

(a) Sodium bicarbonate ($NaHCO_3$, CAS Reg. No. 144-55-8) is prepared by treating a sodium carbonate or a sodium carbonate and sodium bicarbonate solution with carbon dioxide. As carbon dioxide is absorbed, a suspension of sodium bicarbonate forms. The slurry is filtered, forming a cake which is washed and dried.

(b) The ingredient meets the specifications of the Food Chemicals Codex, 3d Ed. (1981), p. 278, which is incorporated by reference…

(c) In accordance with § 184.1(b)(1), the ingredient is used in food with no limitation other than current good manufacturing practice.

(d) Prior sanctions for this ingredient different from the uses established in this section do not exist or have been waived.

GRAS affirmation for sodium bicarbonate, under FDA

The FDA states that sodium bicarbonate is GRAS as a general-purpose food additive at § 582.1736, when used in accordance with good manufacturing or feeding practice.

Specifications for sodium bicarbonate in the Food Chemicals Codex

The third edition of the Food Chemicals Codex (National Research Council, 1981) specifies the following for sodium bicarbonate:

> **Description:** A white crystalline powder. It is stable in dry air, but slowly decomposes in moist air. Its solutions, when freshly prepared with cold water without shaking, are alkaline to litmus. The alkalinity increases as the solutions stand, are agitated, or are heated. One g dissolves in 10 ml of water. It is insoluble in alcohol.
>
> **Identification:** A 1 in 10 solution gives positive tests for Sodium, page 517, and for Bicarbonate, page 516.
>
> **Assay:** Not less than 99.0% of $NaHCO_3$ after drying.
> **Ammonia:** Passes test.
> **Arsenic (as As):** Not more than 3 ppm.
> **Heavy Metals (as Pb):** Not more than 5 ppm.
> **Insoluble Substances:** Passes test.
> **Loss on drying:** Not more than 0.25%.
>
> [Various test descriptions then follow in the monograph and are not listed here.]

Action of the Substance:

Food additive and pH control agent

Sodium bicarbonate is used to improve the water holding capacity in meat products, including chicken, beef, and pork (Åsli & Mørkøre, 2012; Chen et al., 2024). During the first few hours post-mortem, lactic acid from anaerobic respiration begins to rise in muscle tissue, lowering pH (Åsli & Mørkøre, 2012; Puolanne et al., 2002). The lower pH may reduce water holding capacity and juiciness, contributing to the development of a tougher texture after cooking. Sodium bicarbonate is used to both increase the pH and retain water during storage (Chen et al., 2024). The action is similar when sodium bicarbonate is used to process cocoa beans.

Sodium bicarbonate is also used to adjust the pH of cocoa in the Dutching process as described in *Specific Uses of the Substance* (Moser, 2015; Rodríguez et al., 2009). Cocoa beans are naturally between pH 5 and 6 (Moser, 2015); however, the desired pH of cocoa is 8. Sodium bicarbonate raises the pH and aids in the browning reactions that affect the color and yield a less bitter flavor (Rodríguez et al., 2009). When fats are present, sodium bicarbonate may contribute to the saponification of the fats, producing a detectable soap-like taste (Rodríguez et al., 2009).

Leavening agent

The leavening action of sodium bicarbonate results from its decomposition with heat and leavening acids as reactants (De Leyn, 2014; Miller, 2016). Though it can be used alone, it is generally used in acid-base neutralization reactions, with sodium bicarbonate being the chemical base. Sodium bicarbonate reacts with a leavening acid to release carbon dioxide and water (including steam) (see Equation 1, below) (Brown, 2017; Miller, 2016).

$$NaHCO_3 + HA \xrightarrow[heat]{\Delta} NaA + CO_2 + H_2O$$

(sodium bicarbonate) + (acid salt) → (neutral salt) + (carbon dioxide) + (water)

Equation 1

Manufacturers may use sodium bicarbonate without a leavening acid in some cookies or snack crackers (Miller, 2016). In these cases, sodium bicarbonate only partially decomposes under heat (see Equation 2, below) (De Leyn, 2014). Sodium bicarbonate decomposes into sodium carbonate, which may further decompose in acidic conditions to release carbon dioxide gas. While in the oven, sodium bicarbonate releases about half of its weight in the form of carbon dioxide (Gélinas, 2022).

$$2\ NaHCO_3 \rightarrow Na_2CO_3 + CO_2 + H_2O$$

(sodium bicarbonate) → (sodium carbonate) + (carbon dioxide) + (water)

Equation 2

Unreacted and partially reacted sodium bicarbonate affects a product’s taste, pH, and color. Manufacturers can further decompose the sodium bicarbonate by increasing the moisture levels and carefully choosing the leavening acid or acids (De Leyn, 2014). These environmental changes affect the rate of reaction and, therefore, the amount of residue. At the end of a higher moisture decomposition, for example, a sodium salt originating from the acid salt used is produced instead of sodium carbonate (De Leyn, 2014; Miller, 2016). Because of the residue potential, sodium bicarbonate is commonly used with at least one leavening acid. We further discuss taste, pH, and color in *Evaluation Question #4*.

According to Sharma et. al. (2017), the general leavening process can be broken down into three stages:

1. Flour is mixed with water and leavening agents, incorporating all the materials into the dough's structure and creating air pockets.
2. The dough is proofed when necessary.[3]
3. The product is baked, releasing gases and creating a leavening action throughout the dough.

Released gases interact with the air that is introduced as the dough is mixed, and the water in the mixture (Miller, 2016). Air pockets allow for released gas bubbles to expand, using the available air as nuclei for growth (Miller, 2016; van der Sman, 2021). Carbon dioxide is the first and primary gas released into these pockets (De Leyn, 2014; van der Sman, 2021). In double-acting baking powders, carbon dioxide begins its release in the mixing stage, releasing twenty percent of the total (Miller, 2016).[4] The carbon dioxide bubbles expand until they rupture and escape from the dough (van der Sman, 2021). The bicarbonate ion is the only gas contributor until the carbon dioxide bubble rupture event. Water, in the form of steam, escapes from the dough after carbon dioxide (Miller, 2016). The release of carbon dioxide and steam does not affect the pH or color development of the baked product (Gélinas, 2022; Kweon et al., 2014).

Texturization

Because of its leavening action, sodium bicarbonate contributes to the texture of baked goods. A key aspect of leavening is the creation of many small bubbles within the baked product matrix. Sodium bicarbonate produces

[3] Proofing: resting and allowing the dough to rise before baking.
[4] Double acting baking powder: A baking powder made up of a leavening base, two leavening acids, and a carrier such as cornstarch.

carbon dioxide gas bubbles that act as nucleation sites, which expand as they are heated (De Leyn, 2014). As heating continues, steam slowly rises and leaves the product. The resulting baked good has a fine and even texture.

The action of sodium bicarbonate used in meat product texturization is described in the section *Food additive and pH control agent*, above.

Cleaning

Sodium bicarbonate is slightly abrasive and a neutralizing agent for fats and oils. Owing to its alkalinity, sodium bicarbonate neutralizes fatty acids and increases pH. This neutral pH is responsible for sodium bicarbonate's odor-reduction properties (Qamaruz-Zaman et al., 2015).

Combinations of the Substance:

When labeled as sodium bicarbonate, it is commonly available as a single ingredient product without carriers or other additives. However, it also appears in blended products with other ingredients. For example, a tortilla mix product contains sodium bicarbonate blended with less than 1% silica to improve its handling characteristics (Church & Dwight Co., Inc., 2024).

Manufacturers commonly use sodium bicarbonate in combination with other agents to create baking powder. Multiple sources define "baking powder" as a mixture of sodium bicarbonate, one or more leavening acids, and a diluent (De Leyn, 2014; Gélinas, 2022; Penfield & Campbell, 1990). However, this term can be commercially applied to a variety of mixtures that do not include sodium bicarbonate. Foot (1906) noted the original composition of conventional baking powders; we confirmed through a web search of commonly used products that most of the ingredients mentioned on his lists are still used. Some weak acids or acid salts used in conventional baking powder that contains sodium bicarbonate as a main ingredient are:

- monocalcium phosphate
- sodium acid pyrophosphate
- sodium aluminum sulfate
- potassium acid tartrate
- calcium lactate

Baking powder must remain stable for a considerable length of time, but it can be compromised due to moisture absorption (Novitsky, 1957). Increased stability can be achieved by adding a filler such as:

- starch, usually cornstarch
- calcium carbonate
- calcium sulfate

Status

Historic Use:

The use of sodium bicarbonate has been documented since ancient times (Thieme, 2000; Wisniak, 2003). The ancient Egyptians exported nahcolite and sodium sesquicarbonate to other civilizations for use as cleaning agents, mouth cleansers, a component of incense fire, and a component of mummifying materials.

Sodium carbonate can be obtained from mining of an ore called "trona" (Kent et al., 2017). Trona ore (sodium sesquicarbonate dihydrate) is rare in the European Union, and so sodium carbonates are produced almost entirely from the Solvay process there (European Commission, 2007). However, in the United States, trona is plentiful, with roughly 95% of all worldwide deposits (Kent et al., 2017). The European production history is described in this section while the United States mining process is described in *Evaluation Question #1(B)*.

In 1775, the French government established a prize for the discovery of a process to obtain sodium carbonate from sodium chloride (Petrauskas et al., 2024). Nicolas Leblanc was the first to manufacture sodium bicarbonate in a large-scale production process in the 1790s (Thieme, 2000; Wisniak, 2003). The now-defunct Leblanc process for sodium carbonate can be described by Equation 3, Equation 4, and Equation 5 (Thieme, 2000):

$$2\,NaCl + H_2SO_4 \rightarrow Na_2SO_4 + 2\,HCl$$

(sodium chloride) + (sulfuric acid) → (sodium sulfate) + (hydrochloric acid)

Equation 3

$$Na_2SO_4 + 2\,C \rightarrow Na_2S + 2\,CO_2$$
(sodium sulfate) + (carbon) → (sodium sulfide) + (carbon dioxide)

Equation 4

$$Na_2S + CaCO_3 \rightarrow Na_2CO_3 + CaS$$
(sodium sulfide) + (calcium carbonate) → (sodium carbonate) + (calcium sulfide)

Equation 5

Leblanc found a way to produce sodium carbonate, a limited resource, and, in the process, sodium bicarbonate. Progress in this research was halted momentarily due to the French Revolution, as the revolutionaries seized Leblanc's factory and resources, namely sulfuric acid, which was used for gunpowder, during the conflict (Wisniak, 2003). During this time, the mixed sodium carbonate material was used in bleaching, soap-making, and glassmaking (Oesper, 1943). A disadvantage of the process was the creation of calcium sulfide and hydrochloric acid, both waste products that caused atmospheric and water pollution (Thieme, 2000).

In 1856, Sylvester Graham Horsford patented the first baking powder made up of monocalcium phosphate and sodium bicarbonate (Civitello, 2017). The patent focused on replacing calcium lost in the flour refining process; the powder was marketed as "yeast powder" due to its leavening action. Sodium bicarbonate and monocalcium phosphate, which also served as the leavening acid used to react with sodium bicarbonate, were sold at pharmacies and individually wrapped in paper to prevent their early mixing.

The wine industry's near collapse in France in the 1850s gave rise to the interest in replacing yeast as a leavener (Civitello, 2017). Upon the discovery that yeast initiated fermentation, combined with a misunderstanding among the general public that the consumption of live yeast contributed to disease, the search for chemical leaveners was accelerated.

As progress was made, researchers attempted to create sodium carbonate from the double decomposition of sodium bicarbonate and sodium chloride by utilizing the Leblanc process (Thieme, 2000). However, the attempts were unsuccessful. At the same time, the Solvay process was created, with the first plant operating in Germany in 1880. By the early 1900s, only a few Leblanc plants were in operation. The last Leblanc facility closed around 1923 (Thieme, 2000). The Solvay process is detailed in *Evaluation Question #1(B)*. The Solvay process is not common in the United States (Kent et al., 2017). Because production of sodium carbonates from trona ore is cheaper, most of its production in the United States is through mining and chemical processing.

Previous assessments of sodium bicarbonate have not detailed the complete manufacturing process of the material, after trona mining. Current sodium bicarbonate manufacturing processes involve treating the ore to one or more synthetic substances or processes. *Evaluation Question #1(B)* details current practices and their relation to NOP 5023-1.

Organic Foods Production Act, USDA Final Rule:

OFPA (Organic Foods Production Act of 1990, 1990) does not include any reference to sodium bicarbonate.

For processing and handling purposes, USDA organic regulations include sodium bicarbonate on the National List [7 CFR 205.605(a)(26)]. The National List specifies that sodium bicarbonate may be used as an ingredient in or on processed products labeled as "organic" or "made with organic (specified ingredients or food group(s))." Sodium bicarbonate was originally included in the first publication of the NOP Final Rule (65 FR 80548, December 21, 2000).

International:

Internationally, sodium bicarbonate is sometimes referred to as sodium hydrogen carbonate and is sometimes included under the term "sodium carbonates." It is generally allowed under other international standards (see below).

International Organic Food Standards: CODEX Alimentarius Commission—Guidelines for the Production, Processing, Labelling and Marketing of Organically Produced Foods (GL 32-1999)

As INS 500ii, sodium bicarbonate is listed under CODEX guidelines Annex 2, Table 3.1: *Additives permitted for use under specified conditions in certain organic food categories or individual food items.* It is allowed for any *function* in organic food production under CODEX guidelines but is limited for use in confectionary products and bakery wares. It is also allowed in dairy products and analogs, but excludes "products of food category 02.0" (fats and oils, and fat emulsions).

International Organic Agriculture Standards: IFOAM – Organics International (International Federation of Organic Agriculture Movements)

As INS 500, sodium bicarbonate is listed under IFOAM guidelines Appendix 4–Table 1: *List of approved additives and processing / post-harvest handling aids*. It is allowed as an additive or a processing and post-harvest handling additive without limitation.

Canada: Organic production systems-General principles and management standards (CAN/CGSB-32.310), Organic production systems-Permitted substances list (CAN/CGSB-32.311)

Sodium bicarbonate (also as "baking soda" under this standard) is listed under Table 6.3–*Ingredients classified as food additives;* and also Table 6.5–*Processing aids*. It is allowed as an ingredient and processing aid without further annotation. Sodium bicarbonate (baking soda) is also listed on Table 7.3–*Food-grade cleaners, disinfectants and sanitizers permitted without a mandatory removal event*, without further annotation.

Europe and United Kingdom (Northern Ireland): European Economic Community (EEC) Council Regulation (EC No. 2018/848 and 2021/1165)

As E 500 ("sodium carbonates"), sodium bicarbonate is listed under Annex V, Part A, Section A1–*Food additives, including carriers*. It is allowed as a food additive in products of plant and animal origin, without further annotation.

Japan: Japan Agricultural Standard (JAS) for Organic Production

Sodium bicarbonate is included as INS 500ii, listed under Annex A: *Additives (for organic processed foods excluding organic alcohol beverages)*, Table A.1–*Additives*. Under this entry, it is limited to the use in confectionery, sugar, prepared legumes/beans, noodles, bread, beverages, processed vegetable products, or processed fruit products; or as a neutralizer in dairy products.

As INS 500ii, sodium bicarbonate is also listed under Annex B: *Additives (for alcohol beverages)* Table B.1–*Additives*. Under this entry, it is allowed for use as an additive in alcohol beverages, without further annotation.

Korea: Republic of Korea (ROK) Korean Organic Act

Sodium bicarbonate is included as INS 500(ii), listed under Annex 1(C)(1): *Substances permitted for use as food additives or processing aids*. Under this entry, it is limited to use as a food additive in cakes, confectionery and liquid tea.

Switzerland: Federal Office for Agriculture (FOAG), Switzerland Organic Ordinances, Organic Farming Ordinance (SR 910.18), EAER Ordinance on Organic Farming (SR 910.181), FOAG Ordinance on Organic Farming (SR 910.184)

Sodium bicarbonate is included as E500 ("sodium carbonates"), listed under Annex 3, Section A: *Authorised food additives, including carriers*. Under this entry, it is allowed for use for the preparation of foodstuffs of plant origin, as well as milk jam (*Dulce de leche*), sour cream butter and sour milk cheese.

Under Section B1: *Directly used technical aids and other products which may be used in the processing of organically produced ingredients of agricultural origin*, sodium carbonates (ostensibly including sodium bicarbonate) are allowed for the use for the preparation of foodstuffs of plant origin and of animal origin.

Under Annex 3a: *Substances which may be used for the production of yeast and yeast products*, sodium carbonates (again, assuming this includes sodium bicarbonate) are listed as permitted for regulating the pH-value of primary yeast and yeast preparations/formulations.

Taiwan: Organic Agriculture Regulations

Sodium bicarbonate is listed under Chapter 2, Section 3: *Food additives allowed to be used*. Under this entry, it is limited to the use as a leavening agent. It is also listed in Chapter 2, Section 1: *Processing, packaging, distribution and sale* (1): *Substances allowed to be used in harmful organism control*.

The *Certification Standard for Organic Agricultural Products and In-Conversion Agricultural Products and Allowable Substances in their Production, Processing, Packaging, Distribution, and Sale* (i.e. the Taiwan organic standards) Chapter 1, Part 1(5)(1) indicates that natural substances, except those prohibited in Chapter 2, are allowed. In other words, the Taiwan organic standard includes both open and closed lists. Nonsynthetic sodium carbonate might be allowed under this standard for purposes other than leavening and harmful organism control.

United Kingdom (Great Britain): Organic Products Regulations (2009), Retained Council Regulations (EC) (834/2007, 889/2008, and 1235/2008)

As E 500 ("sodium carbonates"), sodium bicarbonate is listed under Annex 8, Part A, Section A–*Food additives, including carriers*. It is allowed as a food additive in products of plant and animal origin, for use in dulce de leche, soured-cream butter, and sour milk cheese.

Evaluation Questions

Classification of the Substance:

Evaluation Question #1(A): Describe if this substance is extracted from naturally occurring plant, animal, or mineral sources.

One source of sodium bicarbonate is directly extracted from a mineral (nahcolite). However, this source is not as common as other sources. Further details on this and other sources are described in depth within *Evaluation Question #1(B)*.

Most sodium bicarbonate is produced from sodium carbonate, which is then converted to sodium bicarbonate.

The sodium carbonate used to produce sodium bicarbonate is produced primarily via either the Solvay process, or from the ore, trona. Some sodium carbonate is also produced from brine, in a process similar to that used with trona. Traditionally, sodium bicarbonate produced from the Solvay process has been considered to be a prohibited synthetic. However, both of these processes make sodium *carbonate,* which, regardless of the source, needs to be chemically converted to form sodium *bicarbonate*.

Evaluation Question #1(B): Describe the most prevalent processes used to manufacture or formulate this substance. Include any chemical changes that may occur during manufacture or formulation of this substance.

Sodium carbonate (excluding sodium bicarbonate produced directly from nahcolite) production in the United States fully relies on trona mining and production from sodium sesquicarbonate and nahcolite containing brines, such as those produced through solution mining at Searles Lake, California (Bolen, 2024; Moulton & Santini, 1995). In 2000, 59% of worldwide sodium carbonate production (the main precursor of sodium bicarbonate) was synthesized via the Solvay Process. About 30% was produced by processing sodium carbonate mineral deposits (primarily trona, but also nahcolite), and 11% was produced using other methods like the *modified* Solvay processes (Steinhauser, 2008; Thieme, 2000).[5]

The percentage figures mentioned above have remained relatively stable over the past years. In total, the world's sodium carbonate production was about 65 million tons in 2023 (Bolen, 2024). The total global production of synthetic sodium carbonate in 2023 was approximately 42 million tons, and the production of sodium carbonate derived from mining (mostly trona) amounted to around 23 million tons (Bolen, 2024).[6]

The precise proportion of the world's sodium carbonate utilized as a precursor in sodium bicarbonate production is not clearly documented. However, a patent by Walravens et al. (2014) indicates that in 2008, global production of sodium bicarbonate reached approximately 2.8 million tons, predominantly derived from the carbonation of sodium carbonate derived from trona or the Solvay process and its variants; it is unclear if this figure also includes sodium bicarbonate directly produced from nahcolite. Natural Soda LLC, based in Colorado, is the only producer of sodium bicarbonate directly from nahcolite deposits that we could identify. According to Scott-Thomas (2010), the maximum production capacity of Natural Soda's facilities is estimated at around 250,000 tons of sodium bicarbonate per year.[7] This quantity represents approximately 8.9% of the total global sodium bicarbonate production documented by Walravens et al. (2014).

Sodium bicarbonate extraction from nahcolite deposits

Nahcolite deposits of sodium bicarbonate are recovered through solution mining operations in the Green River area of Colorado (Natural Soda, LLC., 2019). Hot, pressurized water is pumped into wells, and the saturated solution is cooled to precipitate sodium bicarbonate. This is the only common process to generate sodium bicarbonate directly from a mineral, without further chemical reactions.

[5] The modified Solvay processes are adaptations of the classical Solvay process that are more environmentally friendly, focusing on minimizing pollution. Many modifications have been proposed, and some are currently practiced by the industry at a small scale (Rahimpour et al., 2024).
[6] This represents about 35% of the global production coming from natural minerals.
[7] According to an email from a representative at Natural Soda in March 2025, the current capacity is approximately 260,000 tons per year (Kirk Daehling, personal communication, March 17, 2025).

Sodium bicarbonate production from sodium carbonate

Regardless of whether sodium carbonate originates from either the Solvay or trona/brine processes, sodium bicarbonate is commonly manufactured by percolating carbon dioxide gas through a carbonation tower that contains a saturated solution of refined sodium carbonate (Bonaventura et al., 2017; Bonfim-Rocha et al., 2019; Phinney, 2002; Walravens et al., 2014). Carbon dioxide reacts with sodium carbonate to produce sodium bicarbonate, which precipitates and is then collected through filtration, centrifugation, drying, screening, and packaging (Kostick, 1995). The carbon dioxide used in sodium bicarbonate production can come from limestone calcination (Bonaventura et al., 2017) or other sources, such as the petrochemical industry (Maharloo et al., 2017).

The manufacturing processes that produce the sodium carbonate precursors are detailed below.

Sodium carbonate precursor production: Solvay process

Steps of the Solvay Process

Thieme (2000) provides a detailed description of the Solvay process and its variations (see Equation 6, below).

$$2\,NaCl + CaCO_3 \rightarrow Na_2CO_3 + CaCl_2$$

(sodium chloride) + (calcium carbonate) → (sodium carbonate) + (calcium chloride)

Equation 6

This reaction does not proceed in a solution under standard conditions. The addition of ammonia and carbon dioxide (not shown in Equation 6) in controlled conditions promotes sodium bicarbonate formation by creating an ammonium bicarbonate intermediate. This process takes place at an industrial scale, as depicted by the following steps (Thieme, 2000):

1. A saturated sodium chloride solution is prepared.
2. Limestone or chalk is calcined to produce and collect carbon dioxide and calcium oxide, which will later be converted into milk of lime (calcium hydroxide) to recover the ammonia (step 8).
3. The sodium chloride (step 1) solution is saturated with ammonia.
4. Sodium bicarbonate is precipitated by introducing carbon dioxide. The carbon dioxide utilized in this step comes from the lime kiln (step 2) or the later calcination step (step 6). In most manufacturing plants, cast iron columns are used for this reaction. The columns are equipped with tubular coolers at the lower part to dissipate the heat of the reaction (see Equation 7, below).

$$NaCl_{(aq)} + H_2O_{(l)} + NH_{3(g)} + CO_{2(g)} \rightarrow NH_4Cl_{(aq)} + NaHCO_{3(s)}$$

(sodium chloride) + (water) + (ammonia) + (carbon dioxide) →(ammonium chloride) + (sodium bicarbonate)

Equation 7

5. Filtering and washing: The columns become coated with precipitated sodium bicarbonate that is recovered by washing liquor fed to the columns. The sodium bicarbonate is separated from the mother liquor in continuous rotary vacuum filters, band filters, and sometimes centrifuges. The mother liquor adhering to the sodium bicarbonate crystals is washed off with condensate produced during production or with softened water.[8]
6. Calcination: Crude sodium bicarbonate obtained after filtering and washing contains impurities like water, ammonium chloride, and ammonium bicarbonate. The crude sodium bicarbonate is heated at about 180 °C to liberate the impurities in the form of carbon dioxide, ammonia, and water vapor through thermal decomposition. The final product is technical-grade soda ash (sodium carbonate) which contains traces of sodium chloride (see Equation 8, Equation 9, and Equation 10, below).

$$2\,NaHCO_{3(s)} \xrightarrow{\Delta} CO_{2(g)} + H_2O_{(g)} + Na_2CO_{3\,(s)}$$

(sodium bicarbonate) $\xrightarrow{\text{heat}}$ (carbon dioxide) + (water) + (sodium carbonate)

Equation 8

[8] Softened water is produced through ion exchange. Ions such as calcium, magnesium, and hydroxide that can create mineral deposits in plumbing are exchanged for more soluble ions, typically sodium and chloride. Some water sources are high in minerals that can create these deposits ("hard water"), while other sources contain minimal amounts of these minerals.

$$NH_4HCO_{3(s)} \overset{\Delta}{\rightarrow} NH_{3(g)} + CO_{2(g)} + H_2O_{(g)}$$

(ammonium bicarbonate) $\overset{\text{heat}}{\rightarrow}$ (ammonia) + (carbon dioxide) + (water)

Equation 9

$$NaHCO_{3(s)} + NH_4Cl_{(s)} \overset{\Delta}{\rightarrow} NH_{3(g)} + CO_{2(g)} + H_2O_{(g)} + NaCl_{(s)}$$

(sodium bicarbonate) + (ammonium chloride) $\overset{heat}{\rightarrow}$ (ammonia) + (carbon dioxide) + (sodium chloride)

Equation 10

7. Reconversion to bicarbonate: Utilizing carbon dioxide from step 2, technical-grade sodium carbonate is reconverted into high-purity sodium bicarbonate through carbonation (see Equation 11, below). This step is similar to how sodium bicarbonate is formed from mineral sources of sodium carbonates.

$$Na_2CO_{3(aq)} + CO_{2(aq)} + H_2O_{(aq)} \rightarrow 2\,NaHCO_{3(s)}$$

(sodium carbonate) + (carbon dioxide) + (water) → (sodium bicarbonate)

Equation 11

8. Recovery of ammonia: The liquid filtrate collected in step 5 contains ammonium carbonate, ammonium hydrogen carbonate, ammonium sulfate, and ammonium chloride. Ammonia is recovered by distillation followed by absorption. Ammonium chloride and carbonate are treated with milk of lime (calcium hydroxide) to displace the ammonia. This ammonia is recycled and used again in step 3. Aqueous calcium chloride is the main waste product of this recovery process. This liquid is often discarded entirely. According to the *Calcium Chloride* Technical Report (2024), some of the liquid produced can be used to create calcium chloride. However, this process is only implemented in a limited number of sodium carbonate plants, as the demand for calcium chloride is relatively low.

Modified Solvay/ammonia-soda processes

There are several variations of the Solvay process that are used for producing sodium carbonate (Thieme, 2000), but not all of them are widely used on an industrial scale or make up a significant portion of the world's total production (Rahimpour et al., 2024). We found that the most common manufacturing variant in the industry is Hou's process, also known as the "Combined Alkali Process."

Hou's process was developed around 1930 and is similar to the Solvay process, except that it produces ammonium chloride instead of calcium chloride as a byproduct (see Equation 7) (ChemEurope, 2024). We were unable to determine exactly how much sodium carbonate is produced by Hou's process. Other Solvay process variations are not described here, as their contribution to global production is minimal.

Production of precursor materials used in the Solvay process: sodium chloride

Conventional or solution mining provides the sodium chloride that is used as a raw material in the Solvay process (Thieme, 2000). In some cases, brine can contain inorganic impurities and is often purified with lime; magnesium ions precipitate as hydroxide and calcium as carbonate in the lime-treatment process.

Production of precursor materials used in the Solvay process: carbon dioxide and calcium oxide precursors

Both of these precursors (carbon dioxide and calcium oxide) are obtained from the calcination of mined limestone or chalk (Thieme, 2000). Much of the carbon dioxide is directly utilized to obtain sodium carbonates. The carbon dioxide produced from the calcination of the limestone is redirected to the carbonator to produce sodium bicarbonate from sodium carbonate (Bonaventura et al., 2017) or released into the atmosphere (Bonfim-Rocha et al., 2019).

In contrast, calcium oxide is used to make milk of lime (calcium hydroxide) and to recycle the ammonia precursor at the end of the Solvay process.

Production of precursor materials used in the Solvay process: ammonia precursor

Commercial ammonia is produced synthetically from atmospheric nitrogen through the Haber-Bosch process (Amhamed et al., 2022; MacFarlane et al., 2020; Pattabathula & Richardson, 2016). Gaseous nitrogen and hydrogen are reacted under high pressure with a metal catalyst to produce ammonia.

The hydrogen feedstock is almost entirely produced by heating methane through a process called steam methane reforming (MacFarlane et al., 2020; Pattabathula & Richardson, 2016). This process produces hydrogen and carbon dioxide as by-products.

Sodium carbonate precursor production: Trona processing

The precursor for the trona process is trona ore, also known as sodium sesquicarbonate, obtained from the mechanical mining of natural deposits. These deposits are found in the Green River District of Wyoming. Trona ore is processed to make sodium carbonate. Sodium carbonate is subsequently converted to sodium bicarbonate through the carbonation process noted earlier.

Monohydrate process

The most prevalent manufacturing process for sodium carbonate related to trona deposits is the monohydrate process (Eggeman, 2001; Thieme, 2000; Toxey/McMillan LLC, 2005). The process is captured in the following steps (Bonaventura et al., 2017; Eggeman, 2001; Muraoka, 1985; Thieme, 2000):

1. Trona (sodium sesquicarbonate) ore is mined and crushed.
2. Calcination: Thermal decomposition of the mined trona takes place in a kiln at temperatures ranging from 100-300 °C, converting the ore's sodium bicarbonate into sodium carbonate (see Equation 12, below):

$$2(Na_2CO_3 \cdot NaHCO_3 \cdot 2\,H_2O)_{(s)} \xrightarrow{\Delta} 3\,Na_2CO_{3(s)} + 5\,H_2O_{(g)} + CO_{2(g)}$$

(sodium sesquicarbonate) $\xrightarrow{\text{heat}}$ (sodium carbonate) + (water) + (carbon dioxide)

Equation 12

3. Dissolution and separation: The calcined ore is dissolved in water to separate the insoluble impurities (silica, sodium silicate, and other waste rock) from the sodium carbonate. The sodium carbonate solution is collected, and solid waste and mud are disposed of in evaporation ponds.
4. Filtering: The saturated solution is filtered through a series of filter presses and treated with activated carbon to remove additional organic impurities.
5. Carbonation: The purified saturated solution is pumped to a carbonation tower, where purified carbon dioxide sourced from the first calcination step is introduced.
6. Crystallization: As the saturated solution moves through the tower, it cools and reacts with carbon dioxide to form sodium bicarbonate crystals (see Equation 11). The crystals are collected at the bottom of the tower and transferred to a centrifuge, where the excess solution is filtered out and recycled.
7. Washing and drying: The crystals are washed with a bicarbonate solution and formed into a crystal cake, which is then dried.

Sesquicarbonate Process

In this method, the ore is first crushed and then dissolved in hot water, followed by calcination. In contrast, the monohydrate process described earlier calcines the trona ore immediately after it is crushed, converting it into a monohydrate before proceeding to the next steps (Rahimpour et al., 2024; Toxey/McMillan LLC, 2005). The main steps of the sesquicarbonate process are as follows (Eggeman, 2001; Thieme, 2000):

1. Dissolving trona ore: Ore is crushed and dissolved in recycled liquor at high temperatures to maximize the amount dissolved.
2. Clarification: The solution is filtered and sent to a series of evaporative cooling crystallizers where sodium sesquicarbonate precipitates.
3. Separation: Crystals are separated by centrifugation, and the liquor is reused in the dissolving step.
4. Calcination: The purified sodium sesquicarbonate is separated according to its particle size and calcined using gas or indirect steam. Sodium carbonate is obtained (see Equation 12).
5. Carbonation: To produce high-purity sodium bicarbonate, the resulting sodium carbonate can be transformed in a bubble reactor (see Equation 11).

Solution mining of trona

Manufacturers utilize various adjusted methods to obtain sodium carbonate from naturally occurring mineral deposits using solution mining techniques.

In Turkish trona deposits (sodium sesquicarbonate), manufacturers inject heated water into the underground ore body to dissolve it, creating a brine solution rich in sodium carbonate and bicarbonate (Ceylan et al., 2009; Eti Soda, 2020). This solution is then pumped to the central processing facility, where it is concentrated by applying heat until a sodium carbonate slurry is obtained. The crystals are then separated out using a centrifuge. Once separated the crystals are dried to produce sodium carbonate powder (Eti Soda, 2020). To recover more sodium carbonate crystals, sodium hydroxide may be added to neutralize some of the purge solutions before they are further processed and crystallized (Ceylan et al., 2009). A portion of the sodium carbonate slurry is then fed into carbonation columns, where sodium bicarbonate crystals are obtained and collected through filtration and drying (Ceylan et al., 2009).

At Searles Lake and Owens Lake, California, brine containing sodium sesquicarbonate may be extracted from strata in dry lake beds through fluid injection (Moulton & Santini, 1995). The composition of the injected fluid may be confidential, or may simply be fresh water (Graves, 2019). The injected fluid dissolves soluble components of evaporite minerals, and the resulting liquid is pumped into carbonation towers. Sodium carbonate in the brine is transformed into sodium bicarbonate, as described throughout this report. These brines also contain commercially valuable borax and sodium sulfate (Kostick, 1995; Moulton & Santini, 1995).

<u>Evaluation Question #1(C): Discuss whether this substance is agricultural or nonagricultural. If the substance is nonagricultural, is it synthetic or nonsynthetic (natural) [7 U.S.C. 6502(22); NOP 5033-1 (Decision Tree for Classification of Materials as Synthetic or Nonsynthetic); NOP 5033-2 (Decision Tree for Classification of Agricultural and Nonagricultural Materials for Organic Livestock Production of Handling)]?</u>

Agricultural or nonagricultural classification

Evaluation of sodium bicarbonate against Guidance NOP 5033-2 *Decision Tree for Classification of Agricultural and Nonagricultural Materials for Organic Livestock Production or Handling* (NOP, 2016b) is discussed below.

1. *Is the substance a mineral or bacterial culture as included in the definition of nonagricultural substance at section 205.2 of the USDA organic regulations?*

Yes. Sodium bicarbonate is a mineral.

Therefore, sodium bicarbonate should be classified as a nonagricultural substance.

Synthetic or nonsynthetic classification

The classification of sodium bicarbonate as synthetic or nonsynthetic has a complex history. Both the historic evaluation [*i.e.,* prior to the publication of Guidance NOP 5033-1 *Decision Tree for Classification of Materials as Synthetic or Nonsynthetic* (NOP, 2016a)], as well as the evaluation of sodium bicarbonate against Guidance NOP 5033-1 *Decision Tree for Classification of Materials as Synthetic or Nonsynthetic* (NOP, 2016a) are discussed below.

With the exception of direct production of sodium bicarbonate from nahcolite, all of the manufacturing processes we include in this report are based on the same premise: manufacturers combine sodium carbonate with carbon dioxide to yield sodium bicarbonate.

<u>Historic classification of sodium bicarbonate, based on the initial classification by the NOSB</u>

During the 1995 NOSB meeting in Orlando, Florida, the NOSB voted to classify sodium bicarbonate as nonsynthetic (NOSB, 2009). Prior to the board's vote, a TAP report was conducted that briefly described the manufacturing process for sodium bicarbonate (NOSB, 1995). Publicly available notes from the NOSB meeting do not contain any further details regarding the decision to classify sodium bicarbonate as nonsynthetic, or which forms are nonsynthetic. The classification recommended by the NOSB in 1995 (NOSB, 2009) was not based on the decision tree in Guidance NOP 5033-1 *Decision Tree for Classification of Materials as Synthetic or Nonsynthetic* (NOP, 2016a), which was not published until 2016.

The 1995 TAP review only discussed two manufacturing processes, neither of them the direct method from nahcolite.[9] Based on the NOSB recommendation and the listing of sodium bicarbonate on 7 CFR 205.605(a) as nonsynthetic, many certifiers and material review organizations consider sodium bicarbonate from trona ore as nonsynthetic, and sodium bicarbonate from the Solvay process as synthetic.

<u>Classification of sodium bicarbonate produced from nahcolite, using NOP 5033-1</u>

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

The substance is mined from natural nahcolite deposits.

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?*

No. Nahcolite is sodium bicarbonate in its naturally occurring mineral form.

[9] The authors of the 1995 TAP report briefly mention brines from Searles Lake, but state they use production methods similar to those used with trona ore.

Thus, the material is nonsynthetic, according to the decision tree, when produced through the nahcolite bed solution mining process.

<u>Classification of sodium bicarbonate produced from the Solvay process, using NOP 5033-1</u>

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

No. The Solvay process utilizes ammonia, a synthetic reactant produced through the Haber-Bosch process. The Solvay process involves a displacement reaction between sodium chloride and ammonia, which takes place in the presence of carbon dioxide, derived from calcium carbonate. This reaction facilitates the formation of sodium bicarbonate. Due to this, the material is synthetic because it is not manufactured from a natural source.

<u>Classification of sodium bicarbonate produced from the carbonation of sodium carbonate, derived from sodium sesquicarbonate (*e.g.,* trona), using NOP 5033-1</u>

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

No. The substance (sodium bicarbonate) is manufactured through carbonation using two precursors (sodium carbonate and carbon dioxide). The sodium carbonate *precursor* is produced by calcining (heating) sodium sesquicarbonate, which is mined. Sodium sesquicarbonate is a double salt of sodium carbonate and sodium bicarbonate. The calcination process decomposes sodium sesquicarbonate, ultimately releasing carbon dioxide and water. This converts the double salt into the single salt, sodium carbonate.

Later, sodium carbonate is further combined with carbon dioxide and water to produce sodium bicarbonate. The carbon dioxide precursor may be derived from the calcination of lime, from carbon dioxide wells, from fermentation processes, from calcination of sodium sesquicarbonate, or from other sources.

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. After the mineral is mined from the ground, sodium sesquicarbonate is transformed into sodium carbonate through calcination (heating). This is a chemical change not dissimilar to the calcination of lime to produce quicklime, where carbon dioxide is removed from the mineral. According to the decision tree, a chemical change caused by heating a mineral results in a synthetic material.

Furthermore, to create sodium *bi*carbonate, the material undergoes another chemical reaction to transform sodium carbonate into sodium bicarbonate via carbonation.

Many, if not all, certifiers and material review organizations currently consider sodium bicarbonate produced from trona ore to be nonsynthetic and therefore the form allowed on the National List at § 205.605(a). Given that the historic classification of sodium bicarbonate produced from trona ore may conflict with the outcome of classification using the Guidance NOP 5033-1 *Decision Tree for Classification of Materials as Synthetic or Nonsynthetic* (NOP, 2016a) decision tree, we note the importance of the NOSB's role in ultimately determining classification and any necessary recommendations to the USDA for regulatory amendments.

<u>Evaluation Question #1(D): Does this substance in its raw or formulated forms contain nanoparticles?</u>

According to NOP Policy Memo 15-2, nanotechnology is conducted at the nanoscale, which is about 1 to 100 nanometers (nm) (NOP, 2015). NOP uses the term "incidental nanomaterials" to refer to substances that are byproducts of other manufacturing (*e.g.,* homogenization, milling) or that occur naturally (NOP, 2015).

The food-grade sodium bicarbonate in the marketplace does not contain intentionally engineered nanomaterials. Nanomaterials that could occur naturally or may be incidental byproducts of human activity are unlikely to be present in sodium bicarbonate because the smallest particle size of common products falls in the micrometric scale at around 30-40 microns (DudaDiesel, 2008; Eti Soda, 2020; Hansen et al., 2014). As described in *Evaluation Question #4*, there is a product consisting of ultrafine sodium bicarbonate on the market with a particle size of about 1 µm, which is still above the nanoscale.

<u>Evaluation Question #1(E): Does this substance in its raw or formulated forms contain ancillary substances?</u>

As described in *Combinations of the Substance*, sodium bicarbonate is generally sold as a single material and does not contain ancillary substances. However, we identified a tortilla blend mix containing sodium bicarbonate mixed with less than 1% silica to improve its handling characteristics (Church & Dwight Co., Inc., 2024).

Evaluation Question #1(F): Is this substance created using excluded methods?
We found no instances in which sodium bicarbonate is produced through excluded methods.

If this substance is manufactured from agricultural raw materials, are those materials derived from genetically engineered crops, or crops resulting from excluded methods?
The substance is not manufactured from agricultural raw materials.

If this substance is manufactured from other biological raw materials (such as those produced by fermentation or enzymatic action), are those biological materials derived from genetically engineered organisms, or crops organisms resulting from excluded methods?
The substance is not manufactured from other biological raw materials.

Evaluation Question #2: Specify whether this 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.
Sodium bicarbonate is considered by the FDA to be Generally Recognized as Safe (GRAS) without limitations other than current good manufacturing practice (21 CFR 582.1736). The FDA notes its use as a general-purpose food additive. See *Approved Legal Uses of the Substance* for more information.

Purpose and Necessity of the Substance:

Evaluation Question #3: Describe whether the primary technical function or purpose of this substance is a preservative [7 CFR 205.600(b)(4)].
One of the primary uses of sodium bicarbonate is as a preservative for meat products (Chen et al., 2024). Sodium bicarbonate aids in delaying the rancid flavor that emerges as lipids oxidize in meats (Wu et al., 2023). Lipids in meats oxidize with atmospheric oxygen or oxygen introduced in packaging (Domínguez et al., 2019). Oxygen causes a breakdown of unsaturated fatty acids, which results in unpleasant smells and a rancid taste. This oxidation leads to a free radical (a reactive atom or molecule with an unpaired electron) in the fatty acid chain (Domínguez et al., 2019). Sodium bicarbonate is an electron donor, which pairs with the unpaired electron and delays the fatty acid breakdown.

Additionally, while meats oxidatively degrade, lactic acid, used as energy in the aerobic respiration process of a living animal, builds up in the meat tissue (Puolanne et al., 2002). After several hours, post-mortem meat drops to pH 5.0 – 5.5, contributing to rancidity. Sodium bicarbonate helps delay this spoilage by increasing the pH and serving as a chemical buffer (Chen et al., 2024).[10]

When used for other purposes (e.g., leavening, texturizing, and cleaning), sodium bicarbonate does not act primarily as a preservative.

Evaluation Question #4: Will this substance primarily be used to recreate or improve flavors, colors, textures, or nutritive values lost in processing (except when required by law)? If so, describe how [7 CFR 205.600(b)(4)].
Sodium bicarbonate affects a product's flavor, color, and texture. Depending on its function, sodium bicarbonate may affect one or more of these properties. However, this is not always the primary intention of sodium bicarbonate addition. Sodium bicarbonate is more often used as a leavener, or added to prevent the development of undesired flavors, colors, or textures rather than added to recreate them. The mechanisms of action are described in *Action of the Substance*.

pH control agent
Sodium bicarbonate is often used as an additive in meat products to improve the texture and flavor of the product (Chen et al., 2024; Zou et al., 2019). Researchers have measured the impact of sodium bicarbonate on different meat products. Chen et al. (2024) studied the prevention of beef meatball oxidation. They also examined curcumin's antioxidant properties as a co-formulant with sodium bicarbonate. The researchers found that sodium bicarbonate helped beef meatballs retain water, and stabilize pH, limiting oxidation. Sodium bicarbonate may also help prevent the loss of water in other meat products, and aids in preserving the umami flavor of broths, such as chicken broth (Chen et al., 2024; Wu et al., 2023).

[10] Buffer: an agent that consists of a weak acid or base and its salt, which combined can resist pH change by neutralizing small amounts of acid or base. Sodium bicarbonate is a basic buffer that neutralizes acids.

Wu et al. (2023) conducted a study to trace the color development and umami flavor in different chicken broths.[11] They found that sodium bicarbonate-treated broths had a higher content of amino acids responsible for the umami flavor, and were darker in color.

Sodium bicarbonate is responsible for the characteristic reddish-brown to black color of cocoa (Rodríguez et al., 2009). Polyphenol oxidase, an enzyme present in cocoa, has an optimal activity at a pH of 8.0. As the pH increases, the cocoa darkens.

No more than approximately 25% of sodium carbonate and bicarbonate dissolve into the final baked good (Gélinas, 2022). Used in excess amounts, sodium bicarbonate remains as a residue that creates an increase in pH, leading to a more intensive browning and an increase in alkaline taste, known as "soda bite" (Canali et al., 2020; Huber & Schoenlechner, 2017a). Strong tastes like ginger may mask an excess amount of sodium bicarbonate.

Leavening agent

As a leavening agent, sodium bicarbonate affects the flavor, color, and texture of baked goods. The leavening action is not intended to recreate flavors, colors, or textures that are lost in processing, but rather to initiate the expected characteristics of the product.

In lower-moisture baked goods (*e.g.,* crackers, dry cookies) the addition of sodium bicarbonate may lead to dark spots in the final product (Gélinas, 2022). This occurs where sodium bicarbonate does not completely dissolve. Ultrafine sodium bicarbonate (particle size = 1 µm) is more efficiently distributed throughout the low-moisture dough than coarse sodium bicarbonate (particle size = 70–90 µm) (Gélinas, 2022). Commercial product searches indicate that the common particle scale is 30–50 µm.

<u>Evaluation Question #5: Describe any effect or potential effect on the nutritional quality of the food or feed when this substance is used [7 CFR 205.600(b)(3)].</u>

Sodium bicarbonate increases the sodium content of baked goods (Institute of Medicine (US) Committee on Strategies to Reduce Sodium Intake, 2010). Ninety-five percent of the sodium in baked goods comes from sodium bicarbonate and table salt. While incorporating sodium bicarbonate may increase the sodium content of other products (e.g., meat products), the literature does not make these explicit nutritive statements.

<u>Environment and Human Health Effects</u>

<u>Evaluation Question #6: List any reported residues of heavy metals or other contaminants in excess of FDA tolerances that are present or have been reported in this substance [7 CFR 205.600(b)(5)].</u>

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 and metal items, such as eating vessels and utensils. Sodium bicarbonate is not included on the list of commodities with action levels (U.S. FDA, 2000).

The latest version of the Food Chemicals Codex specifies limits on impurities in sodium bicarbonate: 2 mg/kg lead (United States Pharmacopeial Convention, 2008). The Food Chemicals Codex does not provide specific limit values for other heavy metals or contaminants in sodium bicarbonate.

<u>Evaluation Question #7: Discuss and summarize findings on whether the manufacture and use of this 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)].</u>

Sodium bicarbonate in food

When used as a leavening agent in baking, sodium bicarbonate partially transforms into sodium carbonate, water, and carbon dioxide. About 75% of the sodium bicarbonate added to the product does not dissolve, and the residue, as well as the sodium carbonate, remains in the final product (De Leyn, 2014). In the environment, sodium bicarbonate is mostly stable in dry air but slowly decomposes in the presence of moisture (PubChem, 2024). Sodium bicarbonate dissolves in water, and once in an aqueous solution, it begins to break up into carbon dioxide and sodium carbonate (PubChem, 2024). Its dissociation also produces bicarbonate and sodium ions. Bicarbonate, carbonate, and sodium ions are ubiquitous in the environment (Gad, 2014; Ouhadi et al., 2011; Poschenrieder et al.,

[11] Umami is one of eight taste profiles (sourness, bitterness, richness, etc.).

2018). At the concentrations used in the food industry, sodium bicarbonate and its breakdown products are unlikely to represent an environmental hazard.

Manufacturing
The industries involved with sodium bicarbonate manufacturing have a more significant environmental impact than food production operations for the reasons explained below and examined thoroughly by Rahimpour et al. (2024) and other authors in this section.

Solvay process and variations
The Solvay process requires significant amounts of limestone and rock salt. Extraction of these deposits from quarries or mines results in dust and fine particle emissions. These emissions can lead to respiratory diseases and harm agricultural land in the surrounding areas (Rahimpour et al., 2024). The purification of the salt brine used as a precursor produces effluents that contain calcium carbonate and magnesium hydroxide. This effluent is combined with other effluents obtained throughout the process (Rahimpour et al., 2024).

The total effluent of the Solvay process is directed to sedimentation ponds, where solid particles settle, and the liquid is disposed of in local waterways or deep underground wells (Eggeman, 2001; Kasikowski et al., 2004; Rahimpour et al., 2024). If the sedimentation ponds are sealed improperly, they can be destroyed during floods, resulting in the release of alkaline compounds into the environment, which could render adjacent lands infertile and pose a serious risk to residents and animals in the area (Rahimpour et al., 2024). An example of the impact of these ponds is the Wilga River, which flows through the sedimentation ponds of the former Soda "Solvay" Plant in Krakow (Likus-Cieślik & Pietrzykowski, 2021). Although the area was revitalized in 1990, the long-term effects of industrial wastewater discharge remain a concern for water quality. Likus-Cieślik & Pietrzykowski (2021) note that years after soda production ended, ongoing pollution from sludge deposition continues to negatively impact the river and that the inadequate insulation of the sedimentation ponds has resulted in significant releases of sodium, calcium, and chlorine into the river system, contributing to water quality levels that are below acceptable standards.

Kasikowski et al. (2004) notes that about 3 million m^3 of waste from the Solvay process is directed to rivers annually. The waste is highly basic, with a pH value higher than 11.5 (Rahimpour et al., 2024), and contains large quantities of calcium chloride (Eggeman, 2001) and other impurities such as calcium hydroxide, sodium chloride, calcium carbonates, sulfates, and magnesium hydroxide (Rahimpour et al., 2024). Steinhauser (2008) notes that higher organisms of benthic communities cannot survive in the alkaline environment of the waste sludge. For instance, the sludge, which deposits on the bottom of water bodies, is lethal for fish eggs.

The Solvay process relies on the calcination of limestone, releasing large amounts of carbon dioxide and carbon monoxide emissions from industrial facilities, and significantly contributing to the greenhouse effect (Rahimpour et al., 2024). Soda ash factories utilizing the Solvay process have a carbon footprint of 1.3 tons of carbon dioxide per ton of sodium carbonate produced (Mond, 2008). However, with improved efficiency and higher environmental standards, the estimated carbon dioxide emissions can be reduced to at least 0.7 tons per ton of sodium carbonate produced.

The dual process (a modified Solvay process), also known as the Hou process, has fewer environmental issues than the classic Solvay process because it eliminates limestone calcination and the ammonia recovery step, but it does produce ammonium chloride. In the past, Japan used ammonium chloride for rice cultivation; however, Rahimpour (2024) notes that this is no longer the case and that ammonium chloride is an undesirable byproduct from an environmental perspective. Conversely, some farms in China still use this compound as a fertilizer (Chai et al., 2017; Sun et al., 2014).

Trona processing
Methane emissions from some trona mines can exceed 30,000 m^3/day due to the presence of organic matter in associated shale deposits (Gangrade et al., 2019). Other toxic gases, such as carbon monoxide and ammonia, which are present in lower concentrations deep underground, are also expelled into the atmosphere during the mining process (Toxey/McMillan LLC, 2005).

Trona mining and processing can also produce "fugitive dust" (sodium carbonate powder) that blows off the tailings ponds and during transport (Toxey/McMillan LLC, 2005). This dust can be seen as white clouds from a distance, and environmental protection measures are in place to collect it.

Both trona-based manufacturing processes (monohydrate and sesquicarbonate) expel carbon dioxide. Part of the expelled carbon dioxide may be used for the carbonation step (Bonaventura et al., 2017), while the rest is released into the atmosphere or compressed and stored to be used for other purposes (Bonaventura et al., 2017; Eggeman, 2001).

Producing one ton of sodium carbonate via trona processing emits approximately 0.138 tons of carbon dioxide into the environment, which is about five times less than the carbon dioxide produced via the Solvay process (IPCC, 2024).

Trona processing requires constant liquor purges to prevent the buildup of impurities on the equipment and final product (Walravens et al., 2014). These purges are disposed of in evaporative ponds, which are toxic to vegetation due to their high salinity and can cause problems for wildlife, particularly waterfowl (Barth & Martin, 1981; Toxey/McMillan LLC, 2005). When waterfowl land in evaporative ponds, their feathers can get coated with sodium carbonate crystals, preventing them from flying and potentially killing them (Jehl et al., 2012). The tailings ponds are hundreds of acres in size (Toxey/McMillan LLC, 2005). For instance, one of Stauffer Chemicals Co.'s tailings ponds is about 400 acres in size (Toxey/McMillan LLC, 2005). In some operations, airboats patrol these ponds full-time, attempting to scare away birds and rescuing those that land in the water (Toxey/McMillan LLC, 2005). Nonetheless, hundreds of salt-encrusted waterfowl, mainly eared grebes (*Podiceps nigricollis*), die yearly at the trona evaporation ponds in southwestern Wyoming.

The greater sage grouse (*Centrocercus urophasianus*) is an endangered bird whose population has declined by 80% since 1965. Most of the surviving sage grouse inhabit the sagebrush ecosystems of Wyoming (Coates et al., 2021); however, the mining and oil industries disrupt their habitats (Pratt & Beck, 2019; Stubberfield, 2019). In 2000, this species was almost listed as endangered by the U.S. Fish and Wildlife Service, but pushback from the Wyoming government, with backing by companies such as the American Natural Soda Ash Corporation, led to the grouse being delisted as a candidate species in 2015 (Stubberfield, 2019). Listing the sage grouse would require federal regulations to mandate the designation of protected habitat, and potentially reduce the exploitable surface of Wyoming by almost one quarter (Stubberfield, 2019). Mineral and hydrocarbon production is critical for Wyoming's economy (Stubberfield, 2019). A recent report by the U.S. Geological Survey indicates that the greater sage grouse population declined nearly 40% since 2002 (Coates et al., 2021).

Solution mining of Searles Lake Beds

Searles Valley Minerals conducts solution mining in Searles Lake to produce trona and other mineral commodities; this requires the use of water, which is a scarce resource in the area. Additionally, the hypersaline industrial wastewater from trona processing is discharged into several man-made ponds spanning over 1,000 acres (Hampton & Yamamoto, 2002). Hampton and Yamamoto (2002) estimated that more than two thousand birds visit the ponds annually. About 25% of these birds die due to the water quality of the hypersaline ponds, which also contain various potentially harmful chemicals, including oil. The migrating birds die from salt toxicosis, salt encrustation, oiling, and possibly other causes.

In 2003, The California Regional Water Board issued a clean-up order (California Regional Water Board, 2003) indicating that IMCC (now Searles Valley Minerals) discharges have created a condition of pollution in Searles Lake waters. The order stated that IMCC uses petroleum hydrocarbon-based solvents, similar to kerosene, in the extraction process. While some of the kerosene is recycled, a portion of it can escape and be included in the effluent of the trona plant. Additionally, the plant effluent contains non-kerosene-type hydrocarbons originating from machine oil drippings. IMCC has also used other chemicals, such as monoethanolamine, formaldehyde, and phenols in their extraction process. During several inspections, visible oil was detected in discharge channels, dredge ponds, and percolating ponds. Samples of the oil revealed that it contained 156,000 ppm of total petroleum hydrocarbons, For comparison purposes, note that soil is considered heavily contaminated with hydrocarbons at 50,000 ppm (Jiang et al., 2016), and that the toxicity of petroleum hydrocarbon fractions in drinking water is low, ranging from 0.7 to 0.0005 ppm (WHO, 2008). The oil was also found in the internal organs of waterfowl; several of them were pronounced dead during the inspections (California Regional Water Board, 2003).

We were unable to locate any clear documentation explaining how the clean-up order was effectively handled.

Nahcolite solution mining

We were unable to find any studies that specifically measured the environmental impact of nahcolite extraction using solution mining. Solution mining can result in land subsidence if the extraction wells are not managed correctly (Warren, 2016).[12] Due to advances in solution mining technologies, incidents of surface sinks and collapses are uncommon today. Similar to solution mining in Searles Lake and trona mining in Wyoming, nahcolite

[12] Land subsidence occurs when large amounts of groundwater are extracted from fine-grained sediments. Since water supports the ground, its removal causes the rocks to compact and sink, this often goes unnoticed over large areas (U.S. Geological Survey, 2018).

solution mining facilities require the creation of tailings ponds. As mentioned earlier, these ponds pose a risk to migrating bird populations, particularly grebes, that are protected by the federal Migratory Bird Treaty Act (Webb, 2015).

Evaluation Question #8: Describe and summarize any reported effects upon human health from use of this 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)].

We found no research describing the direct human health impacts of ingesting sodium bicarbonate at rates observed in processed foods. However, athletes sometimes ingest sodium bicarbonate as an oral performance-enhancing supplement (Grgic et al., 2021). Based on human trials, athletes can reduce the likelihood and severity of digestion tract-related side-effects by limiting doses to 0.2 g/kg body weight or 0.3 g/kg body weight. A range of digestion tract related side-effects (e.g., bloat and abdominal pain) may occur when sodium bicarbonate is administered orally (Grgic et al., 2021; National Center for Biotechnology Information, 2024). This is a consequence of the carbon dioxide gas formed when sodium bicarbonate reacts with stomach acid. Gastric rupture is possible in extreme situations (Thomas & Stone, 1994).

For comparison, these doses are notably higher than the rates of inclusion typically found in processed foods. As a leavening agent, processors may add sodium bicarbonate at rates of 0.5-2.8 g per 100 g of flour (Gélinas, 2022). Furthermore, as a leavening agent sodium bicarbonate generates gas and effectively releases about half its weight as carbon dioxide during the baking process. The inclusion rates of sodium bicarbonate that bakers use for chemical leavening typically do not have adverse effects on human health (Gélinas, 2022).

As an inactive ingredient in pharmaceutical products, sodium bicarbonate is an essentially nontoxic and nonirritant material (Rowe et al., 2009).

The human body metabolizes or breaks down sodium bicarbonate into sodium and bicarbonate ions (Rowe et al., 2009). The sodium ion is eliminated by the kidneys, and the bicarbonate ion becomes part of the body's bicarbonate store. Any carbon dioxide formed via metabolism is eliminated through the lungs. Due to the metabolic pathways involved, excessive amounts of sodium bicarbonate may disturb the body's electrolyte balance. Consequently, this can lead to metabolic alkalosis, the excessive buildup of bicarbonate in body (Rowe et al., 2009). Related to this, risks of acute and chronic oral sodium bicarbonate ingestion include the accumulation of excess bicarbonate levels in body tissues, blood, and urine (National Center for Biotechnology Information, 2024; Thomas & Stone, 1994). Rapid termination of chronic excessive bicarbonate ingestion can result in similar conditions (National Center for Biotechnology Information, 2024).

There is limited evidence that sodium bicarbonate also exhibits anticoagulating effects in human blood. This is an area of continuing research and is currently limited to localized medical applications (Ammann et al., 2023; El-Hennawy et al., 2019). Ammann et al. (2023) demonstrated that it can influence blood platelet function by treating freshly collected human blood with a clinical dose of sodium bicarbonate. The objective of the scientists was to demonstrate the effects of sodium bicarbonate as a localized anticoagulant agent in heart catheters. Sodium bicarbonate, at the amounts used in the study if added directly to blood in the human body, would be instantly diluted.

Sodium overload with potentially serious consequences is also possible. Sodium bicarbonate can cause issues for patients with congestive heart failure or sodium-retaining conditions, including patients with kidney disease (National Center for Biotechnology Information, 2024). The sodium component may cause fluid and/or solute overload and swelling. The risk of solute overload and resultant congestive conditions with edema is directly proportional to the electrolyte concentration administered (National Center for Biotechnology Information, 2024).

Alternatives

Evaluation Question #9: Are there alternative nonsynthetic (natural) source(s) of the substance [7 CFR 205.600(b)(1)]?

Nahcolite is a nonsynthetic form of sodium bicarbonate. As of October 2024, OMRI listed 10 products produced from nahcolite (OMRI, 2024).

As previously described in *Evaluation Question #1(C)*, many certifiers and material review organizations currently consider sodium bicarbonate produced from trona to be nonsynthetic. For more information on the complex classification of sodium bicarbonate, see *Evaluation Question #1(C)*. Since certifiers currently consider sodium bicarbonate produced from trona as nonsynthetic, information is provided below about this source as well. OMRI currently lists 22 sodium bicarbonate products produced from trona ore (OMRI, 2024). However, sodium bicarbonate can be used as an ingredient in other products, and these are not accounted for in this figure.

As described in *Evaluation Question #1(B)*, sodium bicarbonate can be prepared from trona deposits using the following processes:

- trona processing (sesquicarbonate or monohydrate processes)
- solution mining

To make sodium bicarbonate from trona, sodium sesquicarbonate (trona ore) undergoes chemical reactions as described in *Evaluation Question #1(B)*. Manufacturers heat (calcine) sodium sesquicarbonate, which produces sodium carbonate, carbon dioxide, and water. They then use a carbonation step to transform the sodium carbonate into sodium *bi*carbonate.

At least 95 sodium carbonate and sodium bicarbonate deposits have been identified in the world, but only some of them have been quantified (U.S. Geological Survey, 2024)). While there are several minerals containing sodium carbonate, only trona and, more recently, nahcolite are commercially viable (Eggeman, 2001). The most significant natural deposits in the United States (along with their estimated capacity) are included in the list below.

- The trona beds from the Green River Formation in Wyoming are estimated to contain over one hundred billion metric tons of trona, sufficient to satisfy the sodium carbonate world demand for over 2000 years (Eggeman, 2001).
- Searles Lake and Owens Lake in California contain an estimated eight hundred million tons of sodium carbonate reserves (U.S. Geological Survey, 2024).
- The nahcolite resource in the Green River Formation in Colorado, is estimated to be about forty-three billion short tons (Brownfield et al., 2010). However, nahcolite is not economically minable as a separate commodity in all areas because it can be scattered (Brownfield et al., 2010).[13]

Evaluation Question #10: Describe all nonagricultural nonsynthetic (natural) substances or products which may be used in place of this substance [7 U.S.C. 6517(c)(1)(A)(ii)]. Identify which of those are currently allowed under the NOP regulations.

Sodium bicarbonate is uniquely versatile. No single substance can substitute for all of its uses in organic food handling. We discuss nonsynthetic alternatives, organized by use or function below, and briefly discuss possible synthetic alternatives, some of which are allowed in organic processing and handling.

Food additive: pH control

Sodium bicarbonate helps maintain appropriate pH by neutralizing acidic components in foods (Åsli & Mørkøre, 2012; Chen et al., 2024). This pH regulation helps preserve freshness and prevent undesirable changes in taste or texture (Åsli & Mørkøre, 2012; Chen et al., 2024), and also helps control browning during baking (De Leyn, 2014).

There are limited nonsynthetic alternatives to sodium bicarbonate for pH adjustment in food. Calcium carbonate, sodium carbonate, and magnesium carbonate may be synthetic or nonsynthetic. Calcium carbonate is used commonly in wine (NOP, 2018), soft drinks, and cheese, and also provides calcium supplementation (EFSA Panel on Food Additives and Nutrient Sources added to Food (ANS), 2011). Sodium carbonate appears in noodle doughs (Huang & Miskelly, 2016). Nonsynthetic calcium carbonate and sodium carbonate appear on the National List without further annotation at §§ 205.605(a)(6) and 205.605(a)(27), respectively.

Alkalizing is important during various steps in processing chocolate (see *Specific Uses of the Substance*), and producers choose among a variety of mainly synthetic materials in addition to sodium bicarbonate for the specific qualities that each yields in the final product, such as specific color and purity (Moser, 2015; Rodríguez et al., 2009). Potassium bicarbonate is the most common synthetic alternative, but nonsynthetic calcium carbonate and magnesium carbonate are used as well (Barišić et al., 2023; Moser, 2015; Rodríguez et al., 2009).

Leavening

As noted in *Specific Uses of the Substance*, sodium bicarbonate is the most popular chemical leavener because of its low cost, ease of handling, low toxicity, high purity, and lack of noticeable taste (Gélinas, 2022). Because of its popularity, sodium bicarbonate has been widely tested with a variety of leavening acids, and appropriate ratios for

[13] Ton: a unit of weight equal to 2,000 pounds
Metric ton: a unit of weight equal to 2,204.62 pounds
Short ton: Synonym of ton, a unit of weight equal to 2,000 pounds.
Long ton: A unit of weight equal to 2,240 pounds.

given products are well understood (Rodriguez Sandoval et al., 2020). Alternative nonsynthetic leaveners are almost entirely limited to yeast or other microbial fermentation agents.

Most of the alternatives in common use, nonsynthetic as well as synthetic, have proved suitable only in certain products or under specific conditions. For example, sodium bicarbonate works well in quick breads, cakes, and cookies, while yeast adds noticeable flavor and makes products take longer to rise, making it more suitable for breads. Bicarbonates generally work better than carbonates in leavened products; they may free twice as much carbon dioxide in the dough as carbonates (Gélinas, 2022), but they may require an acid to fully react. Recipes rarely describe viable alternatives to directly replace sodium bicarbonate as a leavening agent (Canali et al., 2020).

However, there is some flexibility when selecting alternative leaveners, depending on the product. Off-flavors may be masked by very high levels of sugar or ingredients with a very strong taste, such as ginger (Gélinas, 2022). The particle size of the leavener can also influence reaction rate. For example, producers can use coarser particles of ammonium bicarbonate to slow reactions for dough that is very acidic (such as sourdough bread) or that is stored for long periods under refrigeration (Gélinas, 2022). However, larger particles of sodium bicarbonate may also dissolve incompletely and cause dark spots, especially in crackers and other low-moisture goods (Gélinas, 2022).

Yeast

Yeast is commonly used in higher moisture baked goods such as bread (Miller, 2016; van der Sman, 2021). Although yeast is the most popular leavening agent, it is not an appropriate substitute in most cases because it is typically used in specific types of foods.

For example, yeast is not appropriate for very sweet products. If sugar in a dough exceeds roughly 10% of the flour quantity, yeast cells are destroyed by high osmotic pressure (Neeharika et al., 2020). Too much salt and high temperatures both inhibit yeast survival and activity. Yeast also acts slowly compared to chemical leaveners, and it cannot ferment lactose, the sugar in milk. Yeast needs an acidic environment, and can become unviable in long-term storage (Neeharika et al., 2020).

One advantage of yeast is that spices such as cinnamon, ginger, and cardamom can encourage its activity (Neeharika et al., 2020). Also, yeast flavor is less noticeable when the baker's percentage of added yeast is less than 2.5%, so it may be used in products other than bread in certain recipes (Neeharika et al., 2020). Yeast is available as a certified organic product and is also allowed at § 205.605(a)(30).

Synthetic chemical leaveners

In this section, we describe alkaline components that can serve as direct alternatives for sodium bicarbonate, and do not address complementary leavening acids.

Ammonium bicarbonate (baker's ammonia) can perform its leavening function without an acidulant. However, moisture levels above 5% in baked goods, especially in bulky products, can trap ammonia in the dough, causing an unpleasant ammoniacal flavor (Howard, 2019; Kukurová & Ciesarová, 2024; Miller, 2016). It is therefore less versatile than sodium bicarbonate. In addition, this substance may increase the potential for harmful acrylamide formation (Institute of Medicine (US) Committee on Strategies to Reduce Sodium Intake, 2010; Komprda et al., 2017). Ammonium carbonates are therefore not suitable for products such as cakes and sponges where the moisture content would result in the presence of residual ammonia, unless an additional acidulant is added (Gélinas, 2022).

In baked goods with less than 5% moisture content, such as cookies and crackers, the ammonia gas escapes completely by the end of baking (van der Sman, 2021). Ammonium bicarbonate can yield a more homogeneous pore size, which makes the product softer and increases volume (Huber & Schoenlechner, 2017b). Ammonium bicarbonate appears at § 205.605(b)(4) on the National List.

When used in baked goods, potassium bicarbonate results in a fine crumb structure, and it is often used to reduce the amount of sodium in the product (De Leyn, 2014). If sodium content is not a consideration, additional salt is often added to compensate for flavor. Potassium bicarbonate does encounter less premature reaction compared to sodium bicarbonate (Gélinas, 2022). Potassium bicarbonate has no allowance in organic processing.

Table 3: Properties of leavening agents (De Leyn, 2014; Miller, 2016)

Material	Suitable for	Detectable	National List allowance
Sodium bicarbonate	Most baked goods including cakes, cookies, crackers	No*	§§ 205.605(a)(26) and (27)

Ammonium carbonates	Low moisture goods	No	§§ 205.605(b)(4) and (5)
Potassium bicarbonate	Low sodium goods	Yes	No handling allowance
Yeast	Breads	Yes	§ 205.605(a)(30)

**Sodium bicarbonate does not contribute to taste in small amounts. Larger amounts may cause a bitter taste.*

Food additive: texturizer, tenderizer, water retainer

The yellowing effect of alkali compounds is desirable in noodles and steamed bread. Sodium bicarbonate, sodium carbonate, and potassium carbonate all toughen the dough and make the paste more viscous. They can also act to neutralize sourdough fermentations, which preserves dough structure during steaming (Huang & Miskelly, 2016).

Tenderness is one of the most important factors in the palatability of processed meat products. In addition to chemical interventions, processors also use physical tenderizing techniques (see *Evaluation Question #12*) (Bekhit et al., 2014). Chemical interventions include infusion, marination, or injection with combinations of salts, maltodextrin, starch, and vitamin D (Bekhit et al., 2014).

Saltwater (sodium chloride) and dry salt brines are commonly used to tenderize meat, though they can require more time than sodium bicarbonate. For example, a relatively quick brine of 30 minutes in saltwater would yield similar tenderness to 20 minutes brined in sodium bicarbonate. Salt denatures proteins so they bond with more water, and the meat can become oversaturated, which impairs rather than enhances flavor (Arm & Hammer, 2019). Salt improves the water holding capacity and juiciness of meat by weakening bonds between proteins and making them more soluble. (Åsli & Mørkøre, 2012). Salt and sodium bicarbonate have similar effects that promote water retention during cooking (Sheard & Tali, 2004).

Using salt specifically to improve tenderness or texture of meat is a more recent development than the ancient practices of preservation with salt, including curing and pickling, which began thousands of years ago.

Calcium chloride can also be used as a meat tenderizer, but researchers have found it can adversely affect both the flavor and color of meat (Perez-Chabela et al., 2005; Rousset-Akrim et al., 1996).

Surface cleaner

Processing operations primarily use sodium bicarbonate for removing dirt and debris from surfaces, but it does show some antimicrobial action (Olson et al., 1994). It completely inactivated both antibiotic-resistant and -susceptible bacteria in one study (Rutala et al., 2000). It makes an effective surface cleaner because it is mildly abrasive, saponifies fats and oils, and neutralizes odors.

Alternative cleaning substances include borax (sodium tetraborate, disodium tetraborate decahydrate), kaolin, and sodium carbonate.

In one study, borax performed better than sodium bicarbonate when used to clean bathrooms (Olson et al., 1994). Borax also serves as a pesticide against cockroaches, wood-boring beetles, fleas, and ants (NOP, 2022). Borax does not appear on § 206.605, but it is permitted for processing facility pest management. Guidance in NOP 5023 explains that § 205.271(c) "allows producers and handlers to use nonsynthetic … substances … for facility pest management in accordance with any restrictions." Borax used as a cleaning agent must be completely removed from equipment prior to food contact.

Kaolin is a silicate clay mineral. It is available in formulations with varying particle size according to the specific use. Smaller particle sizes are most effective for polishes, while coarser, more abrasive products can be used in soaps (Murray, 2006). Kaolin products have also been developed for heavily soiled surfaces such as tile and stainless steel (Imerys, n.d.). Kaolin is allowed in organic handling at § 205.605(a)(15).

Sodium carbonate (otherwise known as soda ash or washing soda) softens water, neutralizing calcium and magnesium ions, to enhance the surfactant's effectiveness (Chateau et al., 2004). It works as a glass cleaner, drain cleaner, carpet and floor cleaner, dish detergent, laundry booster and stain remover, and it cleans oven racks and drip pans. Sodium carbonate is caustic, and users should avoid inhalation and skin contact (Eggeman, 2001). Sodium carbonate is also permitted by the National List at § 205.605(a)(26)

Evaluation Question #11: Provide a list of organic agricultural products that could be alternatives for this substance [7 CFR 205.600(b)(1)].

We found limited evidence of organic agricultural products being used as viable alternatives to sodium bicarbonate. Most basic pH control agents (Moser, 2015; Rodríguez et al., 2009) leavening agents, (De Leyn, 2014), and texturizers for noodle dough (Huang & Miskelly, 2016) are nonagricultural, inorganic salts, and they are described in *Evaluation Question #10*. For meat tenderization, processors use a wide variety of alternative practices rather than products. See *Evaluation Question #12*.

Vinegar

Although commonly employed as an antimicrobial, vinegar has also proved more effective than sodium bicarbonate at cleaning soil from surfaces (Olson et al., 1994). However, using nonorganic vinegar as a sanitizer requires an intervening rinse for organic processing operations. Organic vinegar is permitted without restriction.

Evaluation Question #12: Describe if there are any alternative practices that would make the use of this substance unnecessary [7 U.S.C. 6518(m)(6)].

Leavening

As described above (see *Action of the Substance*), the creation of bubbles during mixing is critical in leavening (Neeharika et al., 2020). Air bubbles serve as nuclei for other gases during disproportionation, when smaller bubbles (usually carbon dioxide gas) enter larger ones (usually air). These bubbles can be created by beating, creaming, sifting, folding, etc. (Neeharika et al., 2020; Rodriguez Sandoval et al., 2020). Beating egg whites or cream separately, before incorporating, is another way to leaven a dough or batter in certain recipes that call for those ingredients, such as sponge cakes (Neeharika et al., 2020).

Meat tenderization

Various methods of tenderizing meat exist, but the appropriateness depends on particular situations, and no generic solution exists for all meat products (Bekhit et al., 2014). The toughening of meat post-mortem can be avoided through careful management of endogenous proteases in the tissue (e.g., temperature and pH management, Ca2+ induction, aging) (Bekhit et al., 2014), as well as mechanical and physical means (Hopkins & Smith, 2024). These methods either prevent muscle shortening during rigor, or disrupt the meat structure by physical or enzymatic means when applied after slaughter (Hopkins & Smith, 2024)[14]. Another component of toughness, the amount and structure of connective tissue, is better addressed by the cooking method and temperature rather than post-mortem handling (Bekhit et al., 2014).

High pressure processing (cold pasteurization) is a technology that exerts extremely high pressure on packaged meat that is submerged in water. The pressure kills many types of microbes without affecting the product in the ways that heat and chemical preservatives do (Bhat et al., 2018). Such systems are common in the Meat processing industry and they can play a role in natural meat curing (Bolumar et al., 2021).

Processors also use ultrasound technology for water retention and tenderizing (Al-Hilphy et al., 2020; Bekhit et al., 2014; Wu et al., 2023). At frequencies between 20 kHz and 10 MHz, cavitation bubbles form when the ultrasound generates rarefaction that exceeds the intermolecular attraction forces in the medium (Bekhit et al., 2014). Disrupting the muscle fibers in this way makes the meat more tender. This technology has been investigated for microbe reduction as well as quality measures. Researchers treated samples for 10 to 30 minutes (Roobab et al., 2024). Especially with cured meats, ultrasound improves on traditional time- and energy-intensive methods by yielding predictable results regarding tenderness, pH, and other quality measures in less time than other methods (Li et al., 2024).

Roobab et al. (2024) showed that ultrasonic treatment destabilized collagen fiber structure, and reduced muscle fiber diameter, pH, and cooking loss. They concluded that collagen fibers become disordered, enhancing tenderness, as long as treatment is not excessively intense or long (Roobab et al., 2024). Researchers have investigated hardness, tenderness, shear force, muscle fiber diameter, color, lightness, collagen fiber stability, water holding capacity, cooking loss, chewiness, and amino acid profile using ultrasound variables, including frequency, power, time, and aging. Researchers found that high-frequency treatment increased water holding capacity (Bekhit et al., 2014). In general, exposure time, power, and frequency can all be adjusted to produce various effects on meat (Bekhit et al., 2014; Roobab et al., 2024).

Other physical interventions include (Bekhit et al., 2014; Bhat et al., 2018):

[14] Muscle tissue shortens as it enters rigor, or pre-rigor in temperatures below 10 °C (Hopkins & Smith, 2024). This process is distinct from lactic acid buildup that occurs due to post-mortem anaerobic respiration.

- electrical stimulation
- high temperature conditioning (above 5 °C)
- aging
- freezing and thawing
- mechanical tenderization (e.g., blade tenderization, usually in conjunction with marinades)
- wrapping
- stretching
- hydrodynamic pressure (explosive shockwaves)

Injection and blade tenderization present the risk of contamination, making good hygiene practices very important (Bekhit et al., 2014). Generally speaking, texture softening and protein degradation, while desirable, can harm color stability and meat flavor because they also accelerate oxidative processes (Bekhit et al., 2014).

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