Sulfur

Livestock

Identification of Petitioned Substance

Chemical Names:

Sulfur, Sulphur

Other Name:

Elemental sulfur, Octasulfur, cyclo-S_8, cyclo-octasulfur, cyclooctasulfur, octathiocane, cyclic octaatomic sulfur, orthorhombic sulfur

Trade Names:

Sulfur ground, sulfur powder, sulfur flowers, sulfur, 325 mesh

CAS Numbers:

10544-50-0; 1326-66-5; 7704-34-9

Other Codes:

Pubchem: 66348; InCHI = 1S/S8/c1-2-4-6-8-7-5-3-1; InCHI key = JLQNHALFVCURHW-UHFFFAOYSA-N; Canonical Smiles = S1SSSSSSS1; EC number = 215-437-4, 927-196-9; UNII = 70D1KFU70

Summary of Petitioned Use

A petition was received by the NOP to add sulfur for use as an insecticide (miticide, acaracide) in organic livestock production (§205.603(b)). Sulfur (elemental) is currently allowed for use in the production of organic crops as an insecticide, for plant disease control, and as a plant or soil amendment.

Characterization of Petitioned Substance

Composition of the Substance:

Sulfur is a naturally occurring chemical element. It has been given the symbol S and has an atomic number of 16. It is an abundant, multivalent nonmetal.

Source or Origin of the Substance:

Commercial elemental sulfur was once mined and extracted from salt domes where it sometimes occurs in nearly pure form, but this method has been in decline since the late 20th century. Today, almost all elemental sulfur is produced as a byproduct of coal, natural gas and petroleum refinement (Davis and Detro, 1992). Desulfurization of diesel fuel, gasoline, and jet fuel to meet today's air pollution standards requires the reduction of sulfur concentration from levels exceeding 500 parts per million (ppm) to less than 15 ppm (Song, 2003). Residual sulfur is removed from petroleum, natural gas and coal by the Claus process and refined to very high levels of purity suitable for sulfuric acid production (El-Bishtawi and Haimour, 2004; Elsner et al., 2003).

Properties of the Substance:

Under normal conditions, sulfur atoms form cyclic octa-atomic molecules with chemical formula S_8 (Fig 1). Elemental sulfur is a bright yellow crystalline solid at room temperature. Sulfur is an odorless,

Fig 1. 3-dimensional depiction of cyclooctasulfur (NCBI, 2017)

Table 1. Physical Properties of Cyclooctasulfur*

Chemical formula	S_8
Molar mass	256.48 g·mol^{-1}
Appearance	Vivid, yellow, translucent crystals
Odor	Odorless, or faint odor of rotten eggs if not 100% pure
Density	2.07 g cm^{-3}
Melting point	246°F (119°C; 392 K)
Boiling point	832°F (444°C)
Flash Point	405°F (207.2°C)
log P (Partition coefficient)	6.117
Specific Gravity	2.07@70°F

*NCBI, 2017; Georgia Gulf Sulfur Corporation, 2000

tasteless solid usually sold in blocks or pellets. It is easily crushed into a powder. Sulfur is a reactive element that given favorable circumstances combines with all other elements except gases, gold, and platinum. Sulfur from all sources is available at a purity level of 90-100%, although synthetically produced elemental sulfur purity exceeds 99.9%. Arsenic, selenium, lead, tellurium, cadmium and mercury are found analytically in synthetically produced sulfur at 0.1% or less (Georgia Gulf Sulfur Corporation, 2000).

Specific Uses of the Substance:

Elemental sulfur is granulated to a fine powder (325 mesh) for use as a pesticide (control for mites, insects, fungi and rodents) in livestock production. The particle size for this powder is 44 microns (0.0017 inches) or less. Livestock species include chickens, turkeys, ducks, geese, game birds, pigeons, equine species, cattle, swine, sheep, and goats. Sulfur dusting and or spraying is used for both the animals and their respective accommodations.

Approved Legal Uses of the Substance:

Pesticides are regulated by the US Environmental Protection Agency (EPA). Element sulfur is a ubiquitous, natural component of the environment, but is still required to be registered by the EPA for use as a pesticide. Registration includes evaluation of ingredients, crop or animal, site, frequency, amount, storage and disposal with respect to human health and the environment. The EPA also requires pesticide reregistration at timed intervals to ensure that new potential pesticide issues can be appropriately addressed. EPA has registered sulfur for use as an insecticide, fungicide and rodenticide on several hundred food and feed crops, ornamental, turf and residential sites. Sulfur is applied in dust, granular or liquid form, and is an active ingredient in nearly 300 EPA registered pesticide products. While most of these registrations are for use in crops, the EPA currently considers all registered uses of sulfur to be eligible for reregistration including the use of sulfur as an insecticide for control of mites, insects, fungi and rodents of indoor food animals including sheep, goats, beef/range/feeder cattle, hogs/pigs/swine, poultry and birds (EPA, 1991a).

Sulfur has been known and used as a pesticide since very early times in history, and has been registered for use as a pesticide in the United States since the 1920s. EPA issued a Registration Standard for sulfur in December 1982. The only data requirement imposed at that time was a proposal for crop and facility reentry intervals. No additional generic data have been required since then (EPA, 1991a). Sulfur is exempt from the EPA tolerance establishment requirement (40 CFR §180.1236).

The USDA organic regulations (7 CFR Part 205) currently permit the use of elemental sulfur in organic crop production as an insecticide (including acaricide or mite control), §205.601(e), as plant disease control, §205.601(i) and as a plant or soil amendment, §205.601(j).

Action of the Substance:

Sulfur with a purity of 99.5% or better is recognized as a pharmaceutical product. It has both an antiseptic and a parasiticidal action in lotions, ointments, dusting and dips (Windholz et al., 1983). It has long been known that certain insects are killed to some extent by dry sulfur. The insecticidal properties of sulfur have been shown to be the result of: (1) Its ability to react with oxygen; (2) its ability to soften newly secreted wax on the exoskeletons of insects; and (3) the amount of H_2S formed in its decomposition (Shafer, 1915). More specifically, arthropod respiration is through spiracles that actively open and close to permit air to flow into and out of trachea where oxygen and CO_2 exchange with the arthropod hemolymph: a blood like fluid (Lighton, 1996). Both oxygen and carbon dioxide toxicity can result from defective spiracle function (Kobayahsi et al., 1984; Hetz and Bradley, 2005). Spiracles also prevent water loss. Excessive water loss as a result of spiracle dysfunction can also kill arthropods (Lighton, 1996; Chandrashekhar et al., 1993). Sulfur appears to interact with this mechanism, preventing opening and closing of spiracles, and reducing or preventing airflow and increasing water loss.

Combinations of the Substance:

Sulfur is often used with lime (Windholz et al., 1983). Sulfur can be mixed 1:1 with lard and used as an ointment for the prevention of scaly leg in poultry (Bedford, 1924). Diatomaceous earth or kaolin earth can be combined with elemental sulfur powder in preparations for housing and dustbathing treatments for ectoparasites (Martin and Mullens, 2012).

Status

Historic Use:

Sulfur is already permitted for use as an insecticide (including acaricide or mite control) in organic crop production if requirements of 205.206(e) are met. Producers are also required to use preventative, mechanical, physical and other pest, weed and disease management practice. Sulfur has historically been used for the prevention and treatment of lice, fleas, ticks and mites which cause or carry pathogens for a number of diseases in horses, pigs, cattle and poultry (MRCVS, 1914). Early American farmers burned native sulfur with charcoal to minimize caterpillar infestations (McWilliams, 2010).

Organic Foods Production Act, USDA Final Rule:

Sulfur is currently permitted for several uses in organic crop production. In §205.601(e) sulfur and the sulfur derivative lime sulfur (including calcium polysulfide) are allowed for use as insecticides (including acaricides or mite control). In §205.601(i) sulfur and its derivative lime sulfur are allowed for use in plant disease control. In §205.601(j) sulfur and its derivative sulfurous acid are allowed as soil amendments. In the case of sulfurous acid, sulfur purity of 99% is required. Sulfur is not found on the National List for use in livestock.

Elemental sulfur is a sulfur compound falling into a category defined by §6517 of the Organic Foods Production Act (National List) for sulfur compounds where an exemption can be made so that the National List may provide for its use in an organic farming or handling operation.

International

Canada - Canadian General Standards Board Permitted Substances List (CAN/CGSB-32.311-2015)

Sulfur is permitted by Canada organic standards in livestock production for control of external parasites. Additionally, non-synthetic elemental sulfur and calcium polysulfide (lime sulfur) are listed for crop production for use as a soil amendment where more buffered sources of sulfur are not appropriate, and as a foliar application. Calcium polysulphide is also listed for use on plants as a fungicide, an insecticide and an acaricide for mite control. Sulfur smoke bombs are also listed for use in rodent control when a full pest control program is maintained but temporarily overwhelmed.

CODEX Alimentarius Commission, Guidelines for the Production, Processing, Labelling and Marketing of Organically Produced Foods (GL 32-2013)

Codex Alimentarius guidelines (GL 32-2013) permit the use of sulfur for livestock and livestock products in bee husbandry for pest and disease control. With recognition by the certification body or authority, GL 32-2103 permits the use of sulfur in soil fertilizing and conditioning, and plant pest disease control,

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

Commission Regulation (EC) No 889/2008 permits the use of elemental sulfur (98% pure) as a fertilizer or soil amendment and as a fungicide, acaricide and repellent in organic farming. Sulfur is not permitted for use as an insecticide in livestock.

Japan Agricultural Standard (JAS) for Organic Production

The Japan Agriculture Standard for Organic Production permits the use of sulfur as a fertilizer or soil improvement. Sulfur is not permitted for use as an insecticide in livestock.

International Federation of Organic Agriculture Movements (IFOAM)

The iFOAM norms allow the use of sulfur as a fertilizer and soil conditioner and as a crop protectant in organic crop production. iFOAM allows the use of sulfur for pest and disease control in beekeeping. Sulfur is not permitted for use as an insecticide in livestock.

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

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

Elemental sulfur is a sulfur compound—S_8 (Fig 1). Its use in this petition is a livestock parasiticide. Sulfur is exempt from a residual tolerance (40 CFR 180.1236) and listed as a stabilizer for food use in 40 CFR 180.930.

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

Sulfur is an abundant element on the earth. Elemental sulfur is found in volcanic sites and salt domes. Sulfur was classically mined using the Frasch process in the US as late as the 1920s. In the Frasch process superheated water is pumped into a sulfur deposit to melt the sulfur, which is then brought to the surface with compressed air. Sulfur produced by the Frasch process was 99.5% pure and required no further purification. In some locations sulfur is found near the earth's surface in sulfur craters. Here sulfur from the deposits is broken up and harvested with various kinds of mining equipment ranging from hand carried baskets to modern conveyor systems.

Sulfur is also found in petroleum, natural gas and fossil products from which it must be removed as a legal mandate to avoid the production of sulfur dioxide, a contaminant of the air. Hydrogen sulfide from petroleum refining and fossil fuels is converted to pure sulfur by the Claus process. The Claus process is used to produce the majority of sulfur available today. In a heating and cooling cycle, hydrogen sulfide recovered from fossil products is combusted to form water and elemental sulfur:

$$8\ H_2S + 5\ O_2 \rightarrow SO_2 + 7/2\ S_2 + 8\ H_2O$$

The addition of an aluminum or titanium catalyst permits the reaction of SO_2 formed during combustion with additional molecules of H_2S to yield sulfur and water:

$$2\ H_2S + SO_2 \rightarrow 3\ S + 2\ H_2O$$

In 2015, recovered elemental sulfur and its byproduct sulfuric acid were produced at 103 operations in 27 States. Total shipments were valued at about $933 million. Elemental sulfur production was 8.7 million tons; Louisiana and Texas accounted for about 52% of domestic production. Elemental sulfur was recovered, in descending order of tonnage, at petroleum refineries, natural-gas-processing plants, and coking plants by 39 companies at 96 plants in 26 States. Domestic elemental sulfur provided 64% of domestic consumption. About 11 million tons of sulfur were used in the US in 2015 (USGS, 2016).

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

Elemental sulfur is both a mined mineral and a synthetic product. Although, available commercially the purity of the mined product is not as high as the synthetic form. Sulfur is primarily recovered synthetically by a thermal catalytic process from sulfite and hydrogen sulfide produced during refining and use of fossil products.

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

Sulfur has been used as a pesticide in the United States since the 1920s, and is currently registered for use as an insecticide and fungicide on a wide range of field and greenhouse-grown food and feed crops, livestock (and livestock quarters), and indoor and outdoor residential sites. Although sulfur has insecticidal and fungicidal properties when used as directed, it is also an abundant and ubiquitous element in the natural environment (Brown, 1982, EPA, 2013b).

Elemental sulfur is combusted at volcanic sites, and metabolized by sulfur bacteria to produce hydrogen sulfide that enters the atmosphere. Hydrogen sulfide in the atmosphere makes clouds more reflective producing a cooling effect on the earth. Sulfur in the atmosphere is involved in the prevention of global warming (Blake, 2007, Wingenter et al., 2007). Elemental sulfur is required for the existence of animal and plant life. Available evidence indicates that elemental sulfur is rapidly and extensively incorporated into the natural sulfur cycle via oxidation to sulfate and/or reduction to sulfide with subsequent volatilization (Lovelock, 1974; EPA, 2013b). The sulfur cycle can be simplified to four basic step: 1) mineralization of organic sulfur (e.g. methionine, cysteine) to an inorganic form (H_2S), 2) oxidation of sulfide, elemental sulfur and related compounds to sulfate, SO_4^{2-}, 3) reduction of sulfate to sulfide, 4) microbial immobilization of sulfur compounds and subsequent incorporation into an organic form of sulfur (Shaver, 2014; la Riviere, 1966). A simplified diagram of the natural sulfur cycle is shown in Fig 2.

Hydrogen sulfide entering the atmosphere reacts with oxygen to form sulfur dioxide. In water, sulfur dioxide forms hydrogen sulfite which in excess is responsible for generating acid rain, i.e. fossil fuels containing sulfur that are burned in the presence of air form sulfur dioxide that is subsequently absorbed into rain water. The pH range for acid rain is 4.2-4.4. Acidification of lakes, rivers and streams resulting from acid rain has led to the devastation of ecological communities and has put many on the brink of destruction. Industrial nations recognizing the environmental problems caused by acid rain have reacted by developing processes to remove sulfur from fossil fuels. Recovered sulfur is usually very pure (EPA, 2016).

Table 2 Occurrence of Sulfur in Nature			
Sources			
Natural			
	Volcanic deposits		Mixed with gypsum and pumice stone
			Realgar or ruby sulfur (arsenic sulfide)
	Subterranean deposits		
		Elemental	Sulfur Ore
		Metallic Sulfides	Acanthite, arsenopyrite, bismuthinite, chalcopyrite, cinnabar, cobaltite, copper pyrite, digenite, galena, iron, pyrite, molybdenite, pentlandite, sphalerite
		Non-metallic sulfides	Angelite, anglesite, barite or heavy spar, celestite, gypsum, thenardite
		Hot Springs	Sulfurous water
		Fossil Fuels	Coal, petroleum, natural gas
	Dietary		
		Food	Onion, cabbage, cauliflower, broccoli, oil of garlic, mustard, eggs
		Vitamins	Thiamine, pyridoxine (vitamin B6), biotin
		Amino Acids	Methionine, keto-methionine, cysteine, cystine, homocysteine, cystathionine, taurine, cysteic acid
		Preservatives	Sulfur dioxide
	Biological		
		Biochemicals	Proteins, lipoic acid, coenzyme A, glutathione, chondroitin sulfate, heparin, fibrinogen, ergothionine, estrogens, ferredoxin
		Microorganisms	Aerobic heterotrophic (most fungi and aerobic bacteria), *Desulfo vibrio* and *Desulfo tomaculum*, chemoautotrophic (e.g., thiobacillus), photoautotrophic (Chlorobium and Chromatium)
Industrial			
	Fertilizers		Phosphates and Ammonium sulfate
	Anthropogenic	Combustion of fossil fuels	SO_2, H_2S
from Komarnisky et al., 2003			

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

Elemental sulfur is found naturally and combined with iron and base metals and sulfide minerals. In petroleum, sulfur occurs in a variety of complex molecules. In natural gas sulfur is present as hydrogen sulfide. Sulfur is present in plants, animals and humans in a number of biological molecules. Recovered sulfur is the primary source of sulfur used for industrial applications. It is recovered from sulfur ores, during the refining of oil, and through the purification of natural gas (Komarnisky et al., 2003). Table 2 provides the sources of sulfur in the environment.

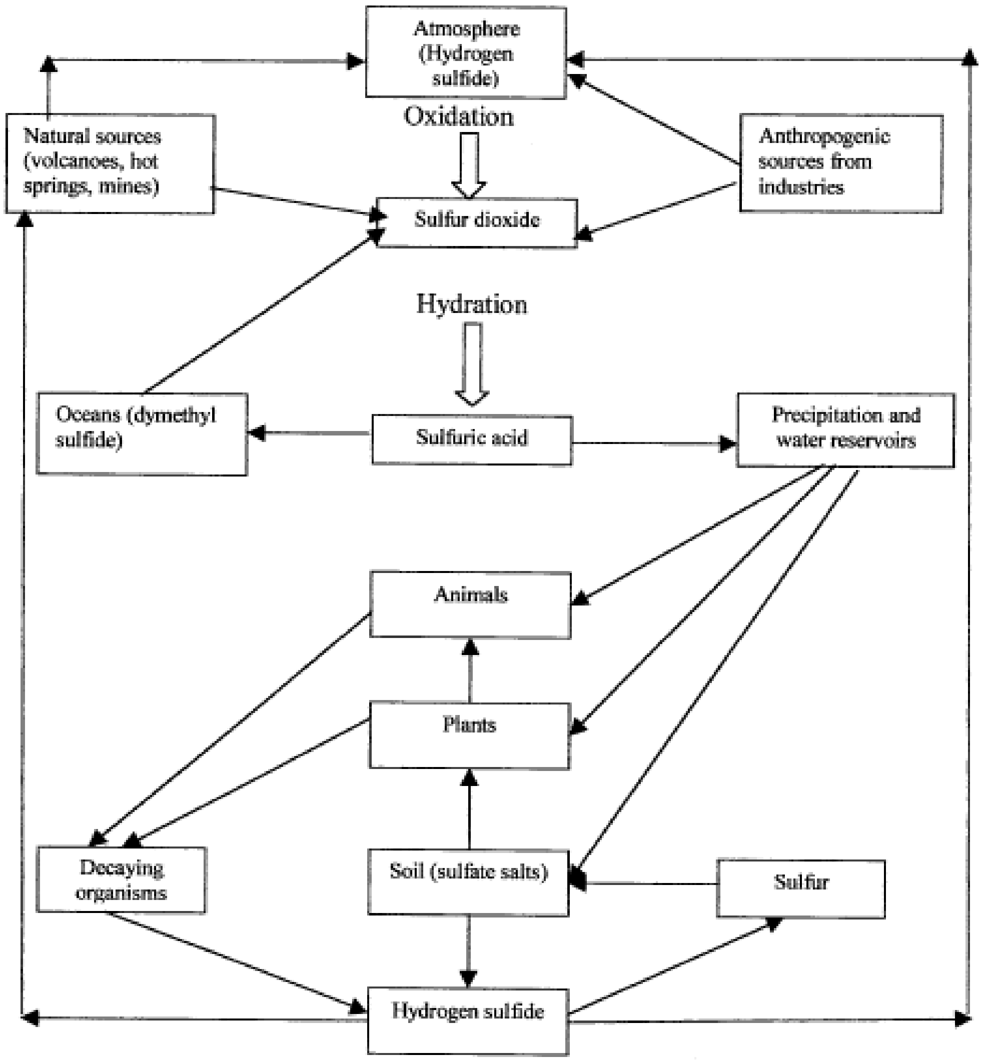

Fig 2. A simplified diagram of the natural sulfur cycle (Komarniskey et al., 2003)

Sulfur is essential for life in a range of concentrations as a part of or in combinations with other molecules. However, sulfur is known to cause polio encephalomalacia in ruminants and may inhibit arachidonic acid metabolism and platelet plasma membrane function in rabbits (Komarniskey et al., 2003). Consumption by ruminants of a high dietary percentage (>0.3%) of sulfur as elemental sulfur or sulfate can cause toxic effects. Sulfur bacteria in the rumen produce the poisonous gases, hydrogen sulfide and sulfur dioxide that eructate from the rumen and are absorbed through the lungs. Diets rich in sulfate can depress feeding. In spite of the liver's capability for detoxifying sulfide in the blood, extreme cases of sulfur toxicity can lead to death (Kandylis, 1984).

Elemental sulfur is insoluble in water. However, its solubility in organic solvents, such as methanol, is greater. Tests with zebrafish larvae showed sulfur toxicity at concentrations as low as 1%. A sulfur concentration that high may be achieved by dilution with methanol (Svenson et al., 1997).

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

Elemental sulfur is transported from mining, manufacturing and transshipping sites in pipelines and in tank cars in molten form. Molten sulfur has the potential to emit hydrogen sulfide gas, which 1) presents a safety hazard to those working in the vicinity and 2) an environmental hazard, since H_2S is very toxic (Sulphur Institute, 2013).

Pollution of the soils can take place where elemental sulfur is stored in the open. Wind eroding fine dust from sulfur blocks or grains stored in the open is deposited downwind of the manufacturing or storage facility. Over several years surrounding soils can become acidified with pH as low as 1. Acidification is the result of soil bacteria converting the sulfur to sulfuric acid. (Nyborg, 1978).

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

Diatomaceous earth, kaolin and lard are natural substances that may be used for organic production. They are used with sulfur for dustbathing poultry to prevent lice and mite infestations. For example, equal parts lard and sulfur can be used to treat birds for the scaly-leg mite. Another treatment for depluming mites uses a combination of ¾ oz. sodium fluoride (not on the National List), 2 oz. sulfur, ½ oz. of household soap and 1 gallon of water. For lice, a dust bath containing sulfur and lime is effective (Rumball, 1927). In the treatment of the hen house for mites, lice and fleas, it is recommended to not only clean and coat surfaces, but to dust with a 3:1 combination of powdered slacked lime and sulfur (Herrick, 1915). When sulfur is used to treat honeybee colonies for mites, no changes in the hedonic performance of the honey is observed in comparison to a water spray control (Hosamani et al., 2007). Sulfur is not toxic to the honey bee (Kuan and Chi, 2007)..

Windblown elemental sulfur from storage piles can result in heavy local deposits: 1 to 100 metric tons/hectare or more. These soils become completely barren with pH 1 to 2. Reclamation is possible by adding large amounts lime, $CaCO_3$ (Nyborg, 1978).

Sulfur as an element is not particularly flammable. However, combining sulfur with potassium chlorate can produce a very unstable, even explosive mixture (Tanner, 1959). Strong oxidizers such as perchlorates, peroxides, permanganates, chlorates can react with sulfur spontaneously cause a fire or explosion (NJ Health, 2011).

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

Elemental sulfur is generally used for livestock insecticide applications in granular or finely powdered form. Liquids and mixtures are also in use. Small amounts of dusting sulfur or liquids find their way into soils or water, either as part of the manufacturing process, transport and storage or application to animals. None of these applications is recognized as an environmental problem (EPA, 1991b). In soils, sulfur is oxidized to sulfuric acid (H_2SO_4) by soil bacteria mostly of the genus *Thiobacillus*. Important factors for the rate of oxidation include 1) the fineness of the sulfur particles, 2) the resident population of *Thiobacillus* spp., 3) soil temperature and 4) soil moisture content. Powdered sulfur is quickly oxidized (Nyborg, 1978). In general there is very little effect on the vegetation, soil or the invertebrate population of the soil from small amounts of sulfur dust. Too much sulfur, e.g. from a sulfur storage or manufacturing facility will cause the pH of the soil to drop as low as pH 2.5 or lower. Although, H_2SO_4 in the soil can generally diffuse in the soil as a sulfate ion leachate, the introduction of high levels of sulfur can cause the loss of vegetative ground cover and affect a number of insect taxa (Carcamo et al., 1998). High sulfur contamination and subsequent acidification has a clear negative effect on earthworms, snails, and several ground beetle species. Among the beetles, ecological specialists are those most vulnerable to acidification, whereas ecological generalists are more resistant (Carcamo and Parkinson, 2001). Earthworms have an important influence on the sulfur turnover in the soil caused by their burrowing, feeding, digestion and egestion (Grethe et al., 1996).

Many species of sulfur reducing bacteria produce and metabolize elemental sulfur in a number of chemical transformations, both in soils and water. Quite a few of these have not yet been identified or characterized. In some cases, particularly in the absence of sufficient nitrate, hydrogen sulfide is produced in the metabolism of elemental sulfur. Hydrogen sulfide is responsible for a serious sulfur odor (Liang, 2016). Livestock operations frequently produce significant levels of hydrogen sulfide, notwithstanding from general practice rather than prevention or treatment for parasites using elemental sulfur (Guarrasi et al., 2015).

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

Sulfur is an abundant element and a significant part of the earth's geochemical equilibrium: gaseous, aqueous and solid. Sulfur products in the environment include elemental sulfur, thiosulfates, sulfites, sulfates, polythionates and polysulfides (Nriagu and Hem, 1978). Natural and industrial activities, such as volcanic action, burning fossil fuels, agriculture, etc. change the geochemical equilibrium, such that the environment becomes polluted, e.g. acid rain, bad smelling air. However, the potential for pollution by elemental sulfur is mostly found in its effect on soils. In soils, the oxidation and reduction of sulfur, the mineralization-immobilization of biologically bound soil sulfur, i.e. amino acids, enzymes, etc., the sorption of SO_2, the formation H_2SO_4 and SO_2 emission by some sulfur fertilizers and the retention and leaching of sulfates play a role in sulfur pollution (Nyborg, 1978). As a fertilizer or amendment, elemental sulfur is oxidized to sulfuric acid in aerobic soils by soil bacteria. Too much can lead to soil acidification. Windblown elemental sulfur from storage piles can result in heavy local deposits (1 to 100 metric tons or more). Soils become completely barren with pH values of 1 to 2. Liming can help to return these soils to a proper pH (Nyborg, 1974).

<u>Evaluation Question #10:</u> Describe and summarize any reported effects upon human health from use of the petitioned substance (7 U.S.C. § 6517 (c) (1) (A) (i), 7 U.S.C. § 6517 (c) (2) (A) (i)) and 7 U.S.C. § 6518 (m) (4)).

Current available US Environmental Protection Agency toxicity studies and literature searches for elemental sulfur do not indicate any systemic toxicity associated with elemental sulfur exposure and no endpoints of toxicological concern have been identified. The acute toxicity of sulfur is low. Acute oral toxicity is a category IV hazard, i.e. fifty percent lethal dose (LD_{50}) is greater than 5000 milligrams (mg) per kilogram (kg) of body weight. Only the word caution or no signal word is required on the label for elemental sulfur for acute toxicity. Elemental sulfur is considered a category III hazard for dermal exposure and inhalation. For dermal exposure, $LD_{50} > 2000$ mg/kg ≤ 5000 mg/kg. Only the signal word caution is required. For inhalation, $LC_{50} > 0.5$ mg/L < 2.0 mg/L and the signal word caution must be on the label. Sulfur is an eye and skin irritant (category III, moderate irritation (erythema) at 72 hours), but is not a skin sensitizer. The EPA is satisfied that in most cases labels contain sufficient information about personal protective equipment and reentry and this information is generally followed by applicators (EPA, 2013a). The EPA's review of incident data indicates that both the relative number of reported incidents and the severity of reported health effects are low.

In livestock production, H_2S is a hazard to human health. This colorless toxic gas with a rotten egg odor is produced during the degradation of liquid manure stored in anaerobic conditions within agricultural livestock operations. In spite of regulatory limits for H_2S exposure of 1 ppm, levels as high as 9, 22 and 97 ppm have been reported for poultry, beef/dairy and swine production, respectively (Guarrasi et al., 2015). The contribution of elemental sulfur to the H_2S livestock production hazard for workers is negligible (EPA, 2013a).

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

Extracts of neem seeds diluted with water or soap have been shown to be effective treatments for mites, ticks, fleas, flies and some insects for livestock (Schmahl et al., 2010). Pest control in poultry production depends upon the production system. In cage free production, where chickens can partake in dustbathing behaviors, both kaolin and diatomaceous earth in the dust bath can serve as a good treatment for mites and lice (Martin and Mullens, 2012). Several essential oils have been shown to be effective against lice and ticks (Rossini et al., 2008; Jaenson et al., 2005)).

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

In livestock production, control of parasites living on the outside of animals (ectoparasites, e.g. mites) and in their housing should focus on excluding vectors such as wild animals and rodents from the production system. Pens and housing should be kept clean. In addition, caretakers should ensure that they do not transfer mites, ticks or lice from an infected population a non-infected one. This can include placing baits and traps near the production facility for both the ectoparasites and their vectors, removing spilled feed, and monitoring rodent and wild bird activity. Buildings should be painted and sealed. Wood buildings must be treated to prevent infestation. In addition, livestock should be monitored regularly for infestations. Wild animal populations in fields, pastures, activity areas and forage should be monitored and potentially infested animals should be sequestered from un-infested herds. Forage and pasture conditions should be monitored, since ectoparasite load is often affected by the extent of grass cutting. Livestock lines that are generally resistant to ectoparasite infestation should be chosen for breeding (Yakout and Wells, 2013).

Biological control of ectoparasites with pathogens such as nematodes, bacteria, fungi and viruses and predators that naturally prey on ectoparasites of livestock are potentially useful in ectoparasite management. For example, both parasitic wasps and the common bacterium, *Bacillus thuringensis* may be useful to protect sheep from various infesting flies, where the bacteria is also effective against lice. Some pathogenic fungi also selectively attack flies, lice and ticks (Wall, 2007).

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