United States Department of Agriculture
Agricultural Marketing Service | National Organic Program
Document Cover Sheet
https://www.ams.usda.gov/rules-regulations/organic/national-list/petitioned

Document Type:

☐ **National List Petition or Petition Update**

A petition is a request to amend the USDA National Organic Program's National List of Allowed and Prohibited Substances (National List).

Any person may submit a petition to have a substance evaluated by the National Organic Standards Board (7 CFR 205.607(a)).

Guidelines for submitting a petition are available in the NOP Handbook as NOP 3011, National List Petition Guidelines.

Petitions are posted for the public on the NOP website for Petitioned Substances.

☒ **Technical Report**

A technical report is developed in response to a petition to amend the National List. Reports are also developed to assist in the review of substances that are already on the National List.

Technical reports are completed by third-party contractors and are available to the public on the NOP website for Petitioned Substances.

Contractor names and dates completed are available in the report.

Narrow-Range Oils

Crops

Identification of Petitioned Substance

Chemical Names:
Mineral oil

Other Names:
Aliphatic solvents; Dormant oils; Foliage oils; Foliar oils; Horticultural oils; Insecticidal oils; Narrow-range oils; Neutral oils; Paraffinic Oils; Petroleum-derived spray oils; Petroleum distilled spray oils; PDSOs; Petroleum spray oils; PSOs; Refined Petroleum distillates; Spray oils; Summer oils; Superior oils; Supreme oils.

Selected Trade Names:
415 Oil; 440 Oil; Superior (440) Spray Oil; BVA Spray 10; BVA Spray 13; Calumet Dormant Spray Oil; Gavicide Green 415; Gavicide Green 440; JMS Stylet Oil®; OMNI Oil 6; OMNI Oil Supreme; PureSpray Green Horticultural Oil; Safe-T-Side Miticide / Insecticide 800EL; Safe-T-Side Paraffinic Oil; SunSpray; Volck Supreme Spray.

CAS Numbers (see descriptions in Table 2):
8012-95-1; 8020-83-5; 8042-47-5; 64741-88-4; 64741-89-5; 64742-54-7; 64742-55-8; 64742-56-9 64742-65-0; 72623-84-8; 72623-86-0; 72623-87-1

Other Codes:
EPA PC Codes: 063502, 063503
EINECS: 232-455-8 (White mineral oil)
RTECS: PY8030000
SMILES: CCCCCCCC

Summary of Petitioned Use

The scope of review is for narrow-range oils used as dormant, suffocating, or summer oils, both as insecticides (including acaricides or mite control) [7 CFR 205.601(e)(7)] and for plant disease control [7 CFR 205.601(i)(7)]. Because the substance is already on the National List ("Oils, horticultural—narrow range oils as dormant, suffocating, and summer oils"), this report requested by the National Organic Standards Board Crops Committee is in support of the sunset review to provide the most current information in scientific literature.

Because of their complexity and variability, the nomenclature for petroleum and its products is difficult to characterize in detail (Neumann, Paczynska-Lahme, and Severin 1981; Barker et al. 2007). The petroleum derivatives that are used as spray oils are also complex and variable, and have their own specific nomenclature (Davidson et al. 1991; Agnello 2002; Cranshaw and Baxendale 2005; Buteler and Stadler 2011). For these reasons, mineral oils used for pest and disease management are identified by several different names. Mineral oil is generally regarded as an archaic name for petroleum, but the term continues to be used as a descriptor for industrial-, technical-, food-, and pharmaceutical-grade petroleum derivatives. These names sometimes have specific meanings, depending on the context, and are not entirely synonymous with one another.

The U.S. Environmental Protection Agency (EPA), in its 2007 review, referred to the collective category as "aliphatic solvents" identified by 12 different Chemical Abstract Services (CAS) numbers, and this term is sometimes used in the context of EPA's regulatory classifications. Literature reviews refer to the collective category as "petroleum-derived spray oils" or "petroleum distilled spray oils (PDSOs)" (Agnello 2002; Buteler and Stadler 2011). "Mineral oils" and "PDSOs" are used in this review as the most inclusive generic terms.

PDSOs are often referred to by their specific use or distinguished by their chemical and physical properties. As such, these terms cannot be used interchangeably. Dormant oils are used on deciduous trees between leaf-fall and bloom. Foliar or foliage oils are applied to actively growing vegetation, as are summer oils. Summer oils are applied during warmer weather when there is a greater risk of plant damage. Suffocating oils are referred to by their mode of action. Collectively, these applications to live plants are referred to as horticultural oils. Insecticidal oils target arthropod pests, and will often include acaricidal uses, such as the control of mites.

"Petroleum distillates" may refer either specifically to those cuts of crude petroleum that are separated by distillation without further refinement or treatment, or may apply more broadly to cracked and treated petroleum products depending on the context (Barker et al. 2007). Narrow-range oils are identified based on the distillation range. Neutral oils are characterized by a relatively high proportion of saturated hydrocarbons. Paraffinic oils have a relatively high proportion of aliphatic structures. These terms may also appear in the context of the reference cited. Supreme oils are highly refined oils that include many narrow-range oils but may be distilled at higher temperatures and over a wider range. Superior oils are a category of narrow-range summer oils with low phytotoxicity (Cranshaw and Baxendale 2005).

Petroleum distillates can also be used as herbicides (Van Overbeek and Blondeau 1954). These may be called "weed oils," carrot oils, or Stoddard's solvent. Mineral oils that are deliberately applied as herbicides generally have higher levels of polycyclic aromatic hydrocarbons and a lower boiling point than narrow-range oils used as summer, dormant and suffocating oils. As such, they are generally not considered in the same category of horticultural oils and are outside the scope of this review.

Characterization of Petitioned Substance

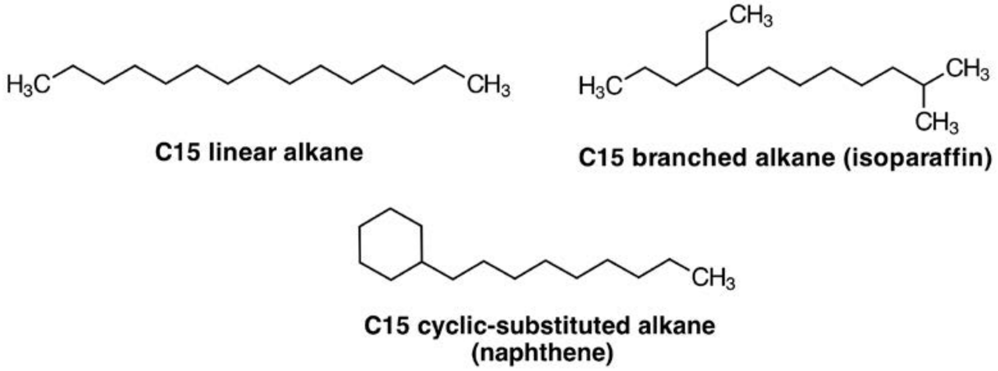
Composition of the Substance:

PDSOs vary according to the source of petroleum, the refining process, and the treatment method. Crude petroleum consists primarily of hydrocarbons, with small amounts of nitrogen- and sulfur-containing compounds, as well as various metals and other non-hydrocarbon impurities. The hydrocarbons in petroleum may be divided into three or four molecular groups based on weight, volatility, molecular structure, and distillation or phase-change from liquid and semi-solid to vapor: the aromatic/cyclic group, the naphthenic/alicyclic group, the aliphatic/paraffinic group (Neumann, Paczynska-Lahme, and Severin 1981; Barker et al. 2007), and—in some cases—the complex hydrocarbons group (Neumann, Paczynska-Lahme, and Severin 1981).

PDSOs are predominately a mixture of long-chain aliphatic (paraffinic) compounds (US EPA 2007) known as alkanes, which belong to the methane series and have the general formula C_nH_{2n+2}. Liquid spray oils are primarily composed of chain structures with 16 to 32 carbon atoms in the chain (Agnello 2002) that may be linear, branched, or have cyclic structures, such as those shown in Figure 1. Alkanes with fewer than 15 carbon atoms are lighter and more volatile; alkanes with 16 or more carbon atoms tend to be more stable at standard temperature and pressure (Neumann, Paczynska-Lahme, and Severin 1981). The EPA recognizes 12 different chemical compounds as meeting the specifications for PDSOs registered as pesticides in the United States. These are classified as technical mineral oil (EPA PC 063502) and aliphatic petroleum hydrocarbons (EPA PC 063503).

Historically, PDSOs have been classified by boiling point and unsulfonated residues; narrow-range oils are paraffinic petroleum distillates with high boiling points and an unsulfonated residue of at least 92 percent (Davidson et al. 1991; Grafton-Cardwell et al. 2008). Molecular weight is now the industry standard for measuring PDSO efficacy and safety for plants because it provides a more accurate representation of a given PDSO's pesticidal properties than less accurate measurement methods using distillation temperatures (Agnello 2002). In addition, although boiling point measurement has mostly been replaced with more analytical methods, gas chromatography is used to measure and clarify the compositions of spray oils with similar boiling points because products are still branded and marketed based on their boiling points. Additional information on classification methods can be found in *Properties of the Substance*.

Figure 1: Molecular structures of linear, branched, and cyclic alkanes.



Source: Pesticide Research Institute 2015.

Source or Origin of the Substance:

Most PDSOs reviewed are produced from the extraction, distillation, and further refinement of petroleum. While it is possible to synthesize aliphatic oils from coal, shale, and natural gas, it is generally uneconomical to do so; thus, synthetic horticultural oils from such non-petroleum sources are not considered in this review. Vegetable oils used as horticultural oils are also outside of the scope of this review, except as non-synthetic alternatives.

Properties of the Substance:

The physical and chemical properties of the different PDSOs vary according to composition, which have implications both for efficacy and phytotoxicity (US EPA 2007). Boiling point was used as a simple measure of PDSOs' efficacy and phytotoxicity (Chapman 1967; Davidson et al. 1991; Weinzierl 2000). Narrow-range oils have a 50 percent boiling point of between 415° and 440°F over a 10–90 percent range of between 60 and 80°F and an unsulfonated residue rating of 92 percent or higher (Weinzierl 2000). Suitability for application as a horticultural oil was determined primarily by the 50 percent boiling point, the 10–90 percent boiling point range determined under atmospheric conditions by method ASTM D447, and the percentage of unsulfonated residues by ASTM method D483 (deOng, Knight, and Chamberlin 1927; P. Chapman 1967; Davidson et al. 1991).

As analytical techniques have improved and understanding of the chemical properties needed to make safe and effective PDSOs has increased, boiling point has been replaced by other testing methods to determine what oil fractions are best suited for that purpose. Boiling point is still measured to serve as a reference point (Grafton-Cardwell et al. 2008). Similarly, previous methods used to determine the narrow-range of petroleum distillates suitable for plant pesticide spray oils are now obsolete (ASTM 2018). Molecular weight through gas chromatography and volatility through vapor pressure are now considered better measures to predict the efficacy, quality and safety of a given PDSO. The industry standard was modified to reflect this new understanding. The primary tests now used to evaluate suitability for use as a petroleum spray oil measure molecular weight and vapor pressure: ASTM D2502, ASTM D2503, and ASTM D2878 (Speight 2015; ASTM 2018). ASTM method D483 is still used to determine unsulfonated residues (ASTM 2018).

The properties of mineral oil are given in *Table 1*;[1] the values are for white mineral oil (CAS 8042-47-5) unless otherwise specified. Mineral oils are generally insoluble in water but may be miscible or emulsified using various non-ionic surfactants. Various organic acid impurities in mineral oil can make the oil acidic (DeOng 1948), while various soluble metallic impurities can make petroleum basic (Neumann, Paczynska-Lahme, and Severin 1981). Mineral oil has no pH because it does not go into solution and is predominately composed of non-polar molecules, so acidity and alkalinity need to be measured by other means (Speight 2015).

---

[1] All tables are contained in the Appendix.

Table 2 summarizes the characteristics of the different chemicals that the EPA classifies as active ingredients in PDSOs. Mineral oil identified as CAS number 8012-95-1 is the broadest category of mineral oil, containing within it all the other items on the list. White mineral oil (CAS 8042-47-5) is the most refined and most consistent, particularly when sold as pharmaceutical- or food-grade.

Specific Uses of the Substance:

The primary use of PDSOs in organic agriculture is on fruit trees as a dormant oil and as a summer oil for the control of soft-bodied insects such as aphids and scales, and to kill the eggs of overwintering insects. It is also used to manage various diseases such as powdery mildew and sooty mold on citrus. *Table 3* contains more information on the pest-crop complexes for which PDSOs are used. Mineral oil is also allowed for topical use and as a lubricant for organic livestock [7 CFR 205.603(b)(6)].

PDSOs are widely used in conventional agriculture, both as active and non-active ingredients. Outside of agriculture, mineral oils have a broad range of industrial, consumer, food, and cosmetic uses.

Approved Legal Uses of the Substance:

EPA Approved Uses

EPA completed its Re-registration Eligibility Decision for aliphatic solvents, which included both mineral oils and aliphatic petroleum solvents, in November 2007 (US EPA 2007). As of September 4, 2018, the EPA Pesticide Product Labeling System lists 190 registered pesticides that had "Mineral Oil" (PC Code 063502) and 34 that had "Aliphatic petroleum solvent" (PC Code 063503) as an active ingredient. *Table 3* lists the crops, pests, and diseases that are labeled for the use of EPA-registered pesticides that fall into these two categories.

Table 3 also summarizes the general timing of application and the legal maximum application rate of mineral oils applied to food crops, based either on pounds of active ingredient per acre per year (lb ai/A) or pounds of active ingredient concentration per gallon (lb ai/gal). Maximum annual application rates vary by the type of equipment used to apply PDSOs, such as airblast, aerial, hand sprayer, or ground boom. Ornamentals, shade trees, and other non-food uses are not included, though mineral oils are labeled for a considerable number of non-food uses as well as the food uses noted below (US EPA 2007; US EPA PPLS 2018).

The EPA also approved several aliphatic solvents for use as inert ingredients in registered pesticides. *Table 4* cross-references the status of the various active ingredients classified by EPA as aliphatic solvents under the current regulation at 40 CFR as well as under EPA's now obsolete list system that formed the basis for determining inert ingredients' status under 7 CFR 205.601(m). Substances not included on the EPA's list were classified as List 3.

The EPA exempts petroleum oils, or mineral oil, from the requirement of a tolerance when applied to growing crops [40 CFR 180.905]. Mineral oils are also exempt from this requirement of a tolerance when used as inert ingredients in pesticide formulations applied to growing or harvest crops [40 CFR 180.910] and directly to animals [40 CFR 180.930]. Previously published at 40 CFR 180.149 was an EPA tolerance of 200 parts per million (ppm) for residues of mineral oil when used ''For post-harvest handling on corn grain and sorghum grain;" the EPA last updated the nomenclature for this listing in 2009 [74 FR 46369-46377]. However, because section 108.149 no longer appears in Subpart C of 180—Specific Tolerances—as of 2010, it is unclear whether this specific regulation is still in force. The exemption from the requirement of a tolerance for mineral oil on growing crops at 40 CFR 180.905 does state in paragraph (c) that the pesticide is not exempted when applied to a crop at the time of or after harvest.

U.S. Food and Drug Administration (FDA) Approved Uses

Several uses of mineral oil are approved by the FDA for human consumption and in animal feed—food-grade white mineral oil, for instance, may be directly added to food [21 CFR 172.340 and 172.878]. FDA-approved uses for mineral oil include as a release agent, binder, lubricant, defoamer, floating agent, dust control agent, and as a protective coating. These uses are subject to specific limitations. Foods that are approved (US FDA 2018) to have white mineral oil as a direct additive include:

- Barley, corn, oats, rice, sorghum, soybeans, wheat
- Dehydrated fruits and vegetables
- Baked goods and confectionaries
- Wine, vinegar, and pickles
- Egg white solids and frozen meat
- Yeast
- Capsules and tablets that contain flavorings, spices, condiments, nutrients, and special dietary supplements

White mineral oil is also approved as an adjuvant with other additives, such as sorbic acid and various polysorbates [21 CFR 172.842]. Synthetic isoparaffinic petroleum hydrocarbons are also permitted as direct food additives [21 CFR 172.882], with permitted uses including froth flotation cleaning of vegetables; as a float on fermentation fluids in making vinegar, wine, and pickles and to prevent contamination with other organisms during fermentation; as a component of coatings on fruits and vegetables; as a coating on egg shells; and as a component of pesticide formulations used on processed foods [21 CFR 172.882(c)]. The FDA also permits food-grade mineral oil to be used as a defoaming agent in processing sugar beets and yeasts, subject to not more than 150 ppm (measured in hydrocarbons) in yeast [21 CFR 173.340(a)(3)].

Mineral oils are allowed on a wide variety of food contact surfaces subject to technical requirements and good manufacturing practices (GMPs) [21 CFR 178.3620] and are widely used in food packaging. Mineral oil may be used in food contact adhesives [21 CFR 175.105(c)(5)], acrylate polymer coatings [21 CFR 175.210(b)], hot melt strippable food coatings on frozen meats [21 CFR 175.230(b)(2)], and as a surface lubricant on resinous or polymeric coatings [21 CFR 175.300]. White mineral oil is also permitted for use in cellophane [21 CFR 177.1200(c)], ethylene-acrylic acid co-polymers [21 CFR 177.1310(b)(2)], oxidized polyethylene [21 CFR 1620(b)], resin-bonded filters [21 CFR 177.2260(d)], and textiles/textile fibers [21 CFR 177.2800(d)(5)] in contact with food. Lubricants used with incidental food contact [21 CFR 178.3570] and in the manufacture of metallic articles that are in contact with food [21 CFR 178.3910] may contain mineral oil. Paper and paperboard used in contact with food is permitted to contain mineral oil [21 CFR 176.170(a)(5)], and paraffin is a major component of waxed cardboard boxes used for produce.

For the broader category of "mineral oil," the FDA found there was insufficient data to support that mineral oil was Generally Recognized As Safe (GRAS) (FDA 2000). The FDA affirmed the narrower category of pharmaceutical (USP)-grade white mineral oil as GRAS when it was subsequently re-submitted (FDA 2001). The amount in food that is considered GRAS is 5 ppm.

Animal feed uses

Food-grade mineral oils may be used in animal feed for/as:

- Dust prevention
- A lubricant in the preparation of pellets, cubes, or blocks
- Preventing segregation of trace minerals in mineralized salt
- A diluent or carrier with food-grade biuret in accordance with GMPs
- Removing water from substances intended as animal feed ingredients [21 CFR 573.680(b)].

FDA set an upper limit of 3.0 percent mineral oil in mineral supplements and 0.06 percent in the total ration when present in feed or feed concentrates [21 CFR 573.680(c)]. However, veterinary products that contain mineral oil as an active substance are considered unapproved animal drugs by FDA, and have not had the necessary safety or efficacy testing completed for FDA approval (Pesticide Research Institute 2015).

Action of the Substance:

Petroleum oils have been thought to have several different modes of action on insects, mites, and plant pathogens. A literature review of the mode of action of PDSOs found that they target multiple sites and do not interact with specific receptors (Buteler and Stadler 2011). Thus, horticultural oils do not behave like most synthetic insecticides. The toxic effects depend on physical and chemical properties of both the oil and the insect. As an ovicide, there is evidence that they prevent atmospheric gas exchange and depress respiration to the point of being fatal to the eggs (Smith and Pearce 1948; Smith and Salkeld 1966). Petroleum oils soften the cuticle, disrupt cuticle waxes, and have teratogenic effects on the epidermis, causing aberrant molts. All of these are fatal to the target organisms (Buteler and Stadler 2011). PDSOs also appear to have some behavioral effects on insects and mites (Buteler and Stadler 2011). These are covered in greater detail in *Evaluation Question #5*.

Combinations of the Substance:

Mineral oil is commonly used as an inert ingredient and adjuvant with other pesticides, as well as a co-active or tank mix ingredient. Formulations of petroleum oil with liquid soap, Bordeaux mix, and/or lime-sulfur were used as combination insecticides, acaricides, and fungicides in fruit production as early as 1917 (Jones 1919). Botanical insecticides have long been formulated using various petroleum oils (Pyenson 1951). The insecticide spinosad may also be mixed with horticultural mineral oils (Taverner et al. 2011). Researchers are experimenting with combinations of PDSOs and biopesticides, including *Isaria fumosorosea,* a fungal pathogen of Asian citrus psyllid (*Diaphorina citri)* (Kumar et al. 2017).

Horticultural oils are often formulated with wetting agents or surfactants that allow them to be mixed and diluted with water. Most spray oils in the United States contain a non-ionic surfactant dissolved in the oil concentrate at a concentration of 0.35 percent for citrus use and 0.5 percent for deciduous use (Davidson et al. 1991; Agnello 2002). Dormant oils have more variation in both the emulsifiers used and their concentration, ranging between 2 and 20 percent emulsifier (Davidson 1991). These emulsifiers are frequently polyoxyethylene (POE) compounds that are made from ethylene oxide. Many are considered confidential business information (CBI).

Status

Historic Use:

Petroleum-derived spray oils were first used as pesticides in the late 1800s, potentially as early as 1868 (Matsumura 1975). By 1880, kerosene had become a standard treatment for the control of aphids, scale, and other soft-bodied insects in deciduous fruit trees (Chapman 1967). Early dormant oil products had highly variable results as an insecticide and sometimes injured the trees during dormancy (Mason 1928). Citrus trees in particular were more susceptible to injury and problems with fruit quality resulting from petroleum oil application (deOng, Knight, and Chamberlin 1927). With dormant oils used on pome and stone fruit, damage was minimal and usually reversible, but for citrus fruit the damage could be severe and permanent. The lightest fractions—composed mainly of aromatic and naphthenic substances—were both toxic to plants and non-toxic to insects. Aliphatic fractions that were non-toxic to plants were also non-toxic to insects, and therefore ineffective. However, above a certain molecular weight, the distillate again became toxic to plants. Thus, to be both effective against insects and non-toxic to plants, petroleum distillates needed to be confined within a narrow range that was eventually determined to be between 415–440°F (approximately 213–227°C) (P. Chapman 1967; Agnello 2002).

A breakthrough occurred when research determined that the most effective and least toxic petroleum distillates had a specific gravity of between 0.8917 and 0.8092 and a viscosity of between 50–350 seconds, and that emulsifying the distillates to spray smaller droplets was both more effective as an insecticide and less harmful to the plants (Volck 1929). The product was named “Volck oil” after the inventor. Research continued to find ways to improve the efficacy and reduce phytotoxicity of petroleum-based spray oils (DeOng 1948; Davidson et al. 1991; Agnello 2002; US EPA 2007; Buteler and Stadler 2011). A parallel set of research set out to increase the phytoxicity of petroleum distillates to enhance their use as herbicides (Van Overbeek and Blondeau 1954).

Dormant oil sprays of miscible petroleum distillates have long been used in organic fruit production programs (Rodale 1961) to control aphids, scale, thrips, and mites (Yepsen 1984). “Dormant” oils were recommended for organic citrus production, but because citrus is non-deciduous and mature trees of most citrus varieties will have fruit at some stage of development throughout the year, the oils are not applied during dormancy. Organic citrus producers were recommended to use very dilute sprays made with highly refined “white oils” (Rodale 1961).

Because of plant damage and quality issues, the use of petroleum oils on foliage during warmer weather was more limited, and the history is not as well documented. Applications to growing foliage were historically called "summer" oils in the research and extension literature, though the oils could be applied in any season (particularly for foliage growing in controlled environments or in tropical or subtropical climates). Therefore, a more accurate description is "foliage" or "foliar" oils (Chapman, Pearce, and Avens 1943; Agnello 2002; Cranshaw and Baxendale 2005).

While summer oils were used on foliage in warm weather, early pest management guides recommended oils for dormant use only (Mason 1928). Improved refinement techniques in the 1930s helped reduce plant injury from petroleum distillates applied in warmer weather (Voorhees 1937). Highly refined white mineral oils with almost all of the unsaturated hydrocarbons removed and an unsulfonated residue of over 90 percent were used both by themselves and with botanical insecticides such as pyrethrum and rotenone (Pyenson 1951). The petroleum distillates were sometimes labeled as co-active ingredients in these formulations but were often declared as "inert ingredients." Historic use of petroleum-derived summer oils on vegetables and other herbaceous annual crops is less well established. Oil emulsion sprays were recommended for aphids that were vectors of beet viruses, but the recommendation referred to corn oil (Yepsen 1984). Foliar application of petroleum oils was used in some certified organic vegetable production prior to the passage of the Organic Foods Production Act, but that historic use is not as well documented as dormant oil or summer oils on citrus and deciduous trees.

Organic Foods Production Act, USDA Final Rule:

Horticultural oils are explicitly mentioned as eligible for inclusion on the National List of Synthetic Substances at 7 U.S.C. 6517(c)(1)(B)(i) and are also included on the National List for use as dormant, suffocating, or summer oils, both as insecticides (including acaricides or mite control) [7 CFR 205.601(e)(7)] and for plant disease control [7 CFR 205.601(i)(7)].

International

Canada

Dormant and summer oils are contained in CAN/CGS- 32.311 Table 4.3. Dormant oils are "[f]or use as a dormant spray on wood plants. Shall not be used as a dust suppressant." Summer oils are limited for use "[o]n foliage, as suffocating or stylet oils." (CAN/CGSB 2015).

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

Table 2 of the Codex Alimentarius Commission's Guidelines for the Production, Processing, Labelling and Marketing of Organically Produced Foods lists "Paraffin oil" as a substance permitted for plant pest and disease control, with the limitation "Need recognized by certification body or authority" (FAO/WHO Joint Standards Programme 1999).

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

Paraffin oil is permitted as an insecticide and acaricide in Annex II of the European Council Regulation governing organic standards (EU Commission 2008).

Japan Agricultural Standard (JAS) for Organic Production

The Japanese Agricultural Standard for Organic Plants, Table 2 allows mixed oil emulsion, petroleum oil aerosol, and petroleum oil emulsion for plant pest and disease control without annotation (Japan MAFF 2000).

IFOAM – Organics International

The IFOAM—Organics International standards Appendix 3 permits the use of "light mineral oils (paraffin)" without annotation for plant pest and disease control (IFOAM 2014).

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

<u>Evaluation Question #1:</u> 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?

(A) The substance is the category of horticultural oils. (B) See *Table 4*.

<u>Evaluation Question #2:</u> 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)).

The product is manufactured from petroleum. The NOSB previously reviewed petroleum refining in the sunset review for mineral oils used in livestock production (Pesticide Research Institute 2015). Crude oil is extracted from the earth either by drilling or from the mining of tar sands.

The crude is washed or steamed with water to remove salt and other water-soluble impurities in the brine that accompanies petroleum (Fahim, Al-Sahhaf, and Elkilani 2009). Demulsifying agents and electricity are used to precipitate the salts. Depending on its weight and viscosity, and the available infrastructure in the oilfield, the crude oil may be transported by pipeline, railcar, truck, or ship. Once the crude oil has had the brine and salts taken out, there are three general steps: 1) crude oil distillation, 2) refinement, and 3) treatment. Each of these steps may have many different processes involved.

Distillation

The crude is distilled as the temperature is slowly raised to separate the fractions that have different evaporation points. The most volatile compounds—generally the simplest (C_1-C_4) hydrocarbons of methane, ethane, propane, and butane—are separated first. These have the lowest molecular weights and boiling points below 32°F (0°C) (Neumann and Rahimian 1984) and need to be condensed as gases or liquified under pressure. Aromatic ring structures such as benzene, toluene, and xylene are distilled at the next highest temperatures. Naphthenic structures are distilled after aromatics. In this range, the fractions used as naphtha, kerosene, gasoline, and diesel are removed. At higher temperatures, the larger aliphatic structures are removed, including the fractions that are used to make petroleum spray oils.

After separating fractions at atmospheric conditions up to a temperature of approximately 800°F (427°C), the residuum is then introduced into a tower under vacuum pressure of 50mm of mercury (Hg) (Fahim, Al-Sahhaf, and Elkilani 2009). The vacuum further extracts the heaviest fractions. The byproducts throughout the process include methane (natural gas), carbon dioxide, ethylene, sulfur dioxide, and hydrogen sulfide. Vacuums are used to increase the efficiency of extraction and to separate fractions of similar boiling points by molecular weight. The heaviest fractions include asphalt and dark, viscous sludges that have a high ash content.

Refinement

The distilled fractions or cuts usually need additional processing to further refine them for use in specific purposes. Certain impurities may be flashed off by high heat or separated by molecular weight or specific gravity. Polar structures such as acids may be removed by ion exchange (Cooper 1977). Immiscible and saturated hydrocarbons, such as phenol and furfural, may also be removed by solvent extraction. Solvents used include furfural, nitrobenzol, dichlor-diethylether, N-methyl pyrrolidone (NMP), and methyl ethyl ketone (MEK) (Neumann and Rahimian 1984; Fahim, Al-Sahhaf, and Elkilani 2009). Further refinement is accomplished through dearomatization, cracking, and wax removal.

Dearomatization

Aromatic hydrocarbons, such as benzene, toluene, and xylene, may be removed by solvent extraction or catalytic conversion. One chemical used to strip aromatics is sulfur dioxide, which is used in the Edeleanu process (Neumann and Rahimian 1984). The pesticide industry has improved techniques for removing the polycyclic aromatic hydrocarbons (PAH) from petroleum spray oils (US EPA 2007). Higher-level treatments involve placing the feedstock in a stirring reactor, where the PAHs will react with added sulfur trioxide or sulfuric acid. The sulfuric sludge will separate and be neutralized with an alkaline reagent—either sodium hydroxide or potassium hydroxide—and then extracted with either ethanol or propanol (EFSA 2012). The process is repeated several times.

Cracking

Distillation by temperature alone is insufficient to obtain petroleum products suitable for making petroleum spray oils. The use of temperatures above the distillation range can break molecular bonds and lead to further separation of more refined cuts—this is called "thermal cracking" (Neumann and Rahimian 1984). More important is the use of various catalysts that cause chemicals in the petroleum to separate in their presence, which is called "catalytic cracking" (Neumann and Rahimian 1984). Catalysts include aluminum silicate, montmorillonite, and zeolites (Decroocq 1984). The reaction of mineral oil with molecular hydrogen (H_2) in the presence of a catalyst at various high temperatures, pressures, and velocities breaks the aromatic and naphthenic ring structures (Parkash 2003). These fragments broken from the heavier ring structures react with the hydrogen to form isoparaffinic or branched alkane structures in a process known as "hydrocracking."

Wax removal

Wax removal is important for preparing petroleum distillates for application as horticultural oils because the wax left after cracking is often phytotoxic. Some wax may be removed in the catalytic cracking process, but residual wax will often need to be removed by crystallizing the wax through rapid cooling to -18°C (0°F), desorbing it with another petroleum solvent such as toluene or MEK, methylation, or flushing it out with ammonia (Neumann and Rahimian 1984; Agnello 2002; EFSA 2012; Pesticide Research Institute 2015). Among the petroleum solvents typically used for wax removal are ketones, benzene, toluene, n-pentane, or propane (Ackerson, Arabshahi, and Babcock 1993).

Treatment

The refined and dewaxed aliphatic fractions may be further treated with various chemicals in a process sometimes referred to as chemical conversion or chemical treatment. PDSOs are often further treated to remove residual PAHs and increase the unsulfonated residue content to meet specifications for horticultural use (US EPA 2007). Treatments may include reaction with various acids, bases, and other highly reactive substances; in particular, the unsulfonated residues of PDSOs can be treated with sulfuric acid (Jacques and Kuhlmann 2002). This treatment step also further lowers the PAH content. Other proprietary substances may be used as absorbents to remove naphthenic and nitrogen structures seen as impurities in spray oils (Agnello 2002).

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)).

Crude petroleum needs to be converted by chemical processes to be useful. There are essentially two types of chemical conversion processes: 1) catalytic methods and 2) thermal methods (Neumann and Rahimian 1984). These account for thousands of chemical reactions that take place in oil refining, including those used to produce horticultural oils. Once converted, the petroleum distillates are further refined by chemical treatments to remove phytotoxic compounds while keeping in the compounds that are toxic to insects and plant diseases.

Petroleum refining, fractionation, and distillation is a chemical process where heat, pressure, and various catalysts are applied to crude petroleum, producing a wide variety of hydrocarbons and other substances. As described in *Evaluation Question #2*, PDSOs are produced by a chemical process that involves thermal and vacuum distillation, catalytic cracking, and hydrogenation, among many other chemical processes. Oil refineries are complex operations with highly specialized chemical processing equipment, including heat exchangers, atmospheric and vacuum distillation columns, fractionation (cracking) towers, alkylation units, viscosity breaking units, coker units, isomerization units, and various strippers for removing various gas (vapor phase) impurities.

The National Organic Standards Board (NOSB) previously determined that mineral oil was synthetic during its initial review in 1995. Mineral oils were also subject to sunset review by the NOSB for use on livestock (Pesticide Research Institute 2015). The NOSB unanimously voted that the substance was synthetic in all previous recommendations (NOSB 1995, 2002).

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)).

Given the complex molecular mixture of PDSOs, it is difficult to generalize about their persistence. Biodegradability and persistence of mineral oils are a function of their chemical and physical characteristics (Haus, German, and Junter 2001). While aromatic structures, particularly PAHs, are more volatile, they are more resistant to biodegradation than aliphatic structures (Haus, German, and Junter 2001). Polar structures also tend to resist biodegradation. A laboratory study found that highly refined paraffinic oils were 75 percent biodegraded in 21 days in secondary-treated sewage effluent (Haus, German, and Junter 2001).

Actual persistence in the field will vary according to temperature, precipitation, sunlight, application method, and droplet size. Research sought to increase the persistence of spray oils to increase efficacy and reduce the rate and number of applications required (Lyman 1939). Dormant oils are usually applied when temperatures are low, when the oil will be more persistent and will provide longer residual effect. However, with foliage oils, persistence increases the risk of phytotoxicity (Agnello 2002). For example, more persistent PDSOs were found to be more effective against citrus leafminer (*Phyllocnistis citrella*) in Australia than less persistent ones (Z. Liu et al. 2001). Although spray oils are not water soluble, they will be washed off with heavy precipitation. Smaller droplets will dissipate more rapidly (Lyman 1939). Thus, the factors that are important for degradation are removed from the active ingredient to the extent that is technically feasible.

The microbial ecology is a principle factor in determining biodegradation rates, given that only certain species are capable of biodegrading petroleum (Zobell 1946; Atlas 1981; Das and Chandran 2011). Biodegradation requires soil temperatures to be sufficiently warm for microbiological activity. Maximum degradation occurs at temperatures between 20° and 30°C (86°–104°F). Soil particle size is also a factor. One study showed that a silty soil treated with petroleum hydrocarbons in laboratory conditions had an over 51 percent microbial degradation rate after 128 days, while a sandy soil had only a 25 percent degradation rate (Scherr et al. 2007). Other factors related to the farming system—such soil type, organic matter content, nutrient content, and tillage practices—may also influence persistence and degradation (Das and Chandran 2011). One study found that lightly fertilized soils degraded crude oil more rapidly than unfertilized soils, but that soils fertilized with relatively high levels of nitrogen, phosphorous, and potassium (NPK) in the soil inhibited biodegradation of crude oil to the point it was not significantly different from the degradation in unfertilized soil (Chaineau et al. 2005). More research is needed to determine how much of a factor farming practices are and specifically the degradation rates under organic farming conditions. PDSOs may also partially biodegrade, with short-chain aliphatic hydrocarbons adsorbing to soil particles for indefinite periods of time. A given set of petroleum hydrocarbons may degrade entirely within days or even hours under one set of environmental conditions and persist indefinitely under a different set of conditions (Atlas 1981).

The EPA is equivocal on the persistence of aliphatic solvents used as pesticide in the environment (US EPA 2007). When used as a surface film on water as a mosquito larvicide, the expected persistence is 2–3 days (US EPA 2007). Its persistence in soil is rated as "low," with an average soil half-life estimated to be 10 days (Vogue, Kerle, and Jenkins 1994). PDSOs do not contain functional groups that undergo photodegradation in ultraviolet or the visible light spectrum (US EPA 2007). However, any aromatic portion would undergo direct photolysis. Oils are insoluble and do not undergo hydrolysis. The oils will biodegrade to an extent, but because of the complexity and size of the molecules in the formulations, they are not considered readily biodegradable and will not rapidly or completely break down into carbon dioxide and water (US EPA 2007). The breakdown products are simpler hydrocarbons that remain adsorbed to foliage to which they are applied and to the soil. The soil organism *Pseudomonas oleovorans* is known to release enzymes that degrade n-alkanes to primary alcohols in the presence of oxygen (McKenna and Coon 1970).

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)).

Compared with other pesticides, aliphatic solvents are relatively non-toxic (US EPA 2007). *Table 5* provides toxicity data for mineral oil, with values for CAS #8012-95-1 or an unspecified aliphatic oil unless otherwise indicated. Highly refined mineral oil mists appear to have low acute and sub-acute toxicity in laboratory animals (HSDB 2015).

The EPA has classified aliphatic solvents as Toxicity Category IV (lowest toxicity—regarded as practically non-toxic) for acute oral toxicity, and primary dermal irritation. Acute dermal and acute inhalation toxicity results were inconsistent depending on the formulation, with some formulated products classified as Category IV and some as Category III (slightly toxic) (US EPA 2007).

Sub-chronic toxicity of mineral oil is also relatively low. While results vary depending on the species and breed of laboratory animals used, the hazards of exposure are considered negligible (Nash et al. 1996). Oral force-feeding of mixed alkanes to Sprague-Dawley rats at doses of 500, 2,500, and 5,000 milligrams per kilogram of body weight per day (mg/kg-bw/day) over 13 weeks resulted in α_{2u}-globulin mediated nephrotoxicity in all groups, and higher liver weights in males at the two higher doses (EFSA 2012). There were also symptoms of irritation and thickening of the stomach mucosa. These symptoms were not regarded to be relevant to human exposure (EFSA 2012). Subsequent studies determined that the No Observed Effect Level (NOEL) for these alkanes was 100 mg/kg/day.

A review of several studies also found that, when ingested by rodents, mineral oil will concentrate in the liver. These studies determined a No Observed Adverse Effect Level (NOAEL) from 0.93 mg/kg to 1,951 mg/kg. The wide range was believed to be in part due to the different chemical and physical characteristics of the oils used (EFSA 2012).

Chronic health effects of petroleum derivatives vary based on their PAH content and how refined they are. The International Agency for Research on Cancer (IARC) found sufficient evidence to support the conclusion that untreated and mildly treated mineral oils are carcinogenic to humans (IARC Group 2). They concluded from the same body of evidence that highly refined oils are not classifiable as to their carcinogenicity to humans (Group 3) (IARC 2012). None of the PDSOs classified as aliphatic solvents by EPA appear on the California Proposition 65 list of chemicals known by the state to cause cancer or reproductive toxicity (Cal-EPA 2018). Food-grade mineral oils that were directly injected into the body cavities of mice induced plasma cell neoplasms and reticulum cell sarcomas (IARC 2012). Repeated exposure of animals and humans to untreated or mildly treated mineral oil mixtures is associated with increased incidence of bladder, scrotal, skin, and stomach cancers (IARC 2012).

The mutagenicity of various mineral oils has been difficult to determine because of the poor water solubility and suspended droplets (US EPA 2007). Ames test results were determined to be unacceptable because the substance could not go into solution when applied to the growth media (Reilly and Stewart 1994). Subsequent tests on other organisms showed no evidence of mutagenicity and the Ames test was not required to be redone for the purpose of pesticide registration (US EPA 2007). A modified Ames test was developed to overcome these problems. The results of this test on food-grade mineral oil were mixed, but on the whole showed a weak mutagenicity (EFSA 2012).

As noted above, PDSOs work by several modes of action. Most studies consider that PDSOs work by a physical, not chemical or toxic, mode of action. Specifically, the oils are thought to block gas exchange in insects and mites, causing the target organisms to suffocate (Moore and Graham 1918; E. H. Smith and Pearce 1948; Johnson 1994; Davidson et al. 1991; Buteler and Stadler 2011; Wins-Purdy et al. 2009). The mode of action can be more broadly linked to penetration of the insect's cuticle, dissolution of internal lipids, and penetration of internal cell structures (Buteler and Stadler 2011). The age or life stage of an insect is an important determinant of susceptibility, with eggs and young larvae being more susceptible than later stage instars, pupae, and adults (Herron et al. 1995). Efficacy varies by the volume, rate of application, and equipment used. Broad and complete coverage is needed to cover the target pest population. High-volume applications that get better coverage are more effective than low-volume or ultra-low-volume sprayers against aphids (Herron et al. 1998) and scale insects (G. A. C. Beattie et al. 1991).

PDSOs have also been observed to modify insect behavior (Buteler and Stadler 2011). For instance, lepidopteran insects have been observed to be significantly less likely to lay eggs on surfaces treated with mineral oil (Larew 1988; Z. Liu et al. 2001; Erler 2004; Wins-Purdy et al. 2009). This egg-laying deterrence is improved by greater persistence (Z. Liu et al. 2001). Insects may also be deterred from feeding on plant surfaces treated with PDSOs (Buteler and Stadler 2011). Minerals oils were observed to repel Asian citrus psyllid, *Diaphorina citri* (Leong et al. 2012; Ouyang et al. 2013; Yang et al. 2013). Various aphids, leafhoppers, psyllids and whiteflies are believed to have their stylets prevented from penetrating leaf surfaces covered with a coating of PDSO (Agnello 2002; Cranshaw and Baxendale 2005; Yang et al. 2013). This mode of action is also thought to reduce transmission of viruses transmitted by these vector insects, such as watermelon mosaic virus and citrus greening (HLB) (Simons 1982; Yang et al. 2013).

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)).

Each step of the petroleum manufacturing process—extraction, distillation, and refining—pollutes air and water and generates a stream of solid waste. A comprehensive review of the environmental contamination of each of these steps is beyond the scope of this review. However, they can each be briefly summarized.

Air Pollution

Greenhouse gases, such as methane and carbon dioxide, are released at wellheads and during the distillation and refining process. The oil and natural gas industry is the largest source of emissions for volatile organic compounds (VOCs) (US EPA 2016). Oil refining releases carbon dioxide, methane, nitrogen oxides (NO_x) and sulfur dioxide into the atmosphere (Petroleum Committee 1964; Amiry, Sutherland, and Martin 1997). While technology for capturing these emissions has improved over the past 20 years, petroleum production and refining remains a major global source of air pollution. Available pollution control technology has not been installed in many cases and air quality continues to degrade—particularly in rapidly developing countries—as petroleum production and consumption increases (Ragothaman and Anderson 2017).

Water Pollution

Petroleum production, transportation, and refining all pose risks for surface and groundwater contamination. Most historic incidents involved offshore oil platform blowouts, such as Deepwater Horizon in the Gulf of Mexico in 2010, or ship tanker mishaps like the Exxon Valdez in 1989 (Allen et al. 2012). However, cumulative leakage may be a greater long-term concern (Allison and Mandler 2018). Groundwater may be contaminated by cracked wellheads and casings, with the pollutants being a mix of crude oil, chemicals used during extraction, and brine water that is mixed with the petroleum deposit. Drilling muds and solvents used to increase the yields of drilling can contaminate groundwater. These are mixed with brine water that is extracted and separated from the crude oil, and naturally occurring radioactive material, including radium. Hazardous waste generated during the extraction process is typically disposed of by deep-well injection. There is evidence that hydraulic fracturing (hydrofracking) increases the risk of water pollution (Allen et al. 2012; NYS DEC 2015).

Petroleum refining may also result in surface and groundwater pollution (Allen et al. 2012). Effluents from petroleum refining include acids, salts, waste oil, sulfides, ammonia, nitrate, cyanides, heavy metals, suspended solids, and various toxic hydrocarbons (Amiry, Sutherland, and Martin 1997; Wake 2005; Allen et al. 2012). Areas near the outfall of petroleum refinery effluent may be almost completely devoid of life (Wake 2005).

Land Use and Soil Contamination

Petroleum and natural gas production can disrupt existing land use patterns (NYS DEC 2015). Horizontal drilling may reduce the amount of land on the surface that is disturbed, but it can also lead to an increased overall area of geological disturbance (Allison and Mandler 2018). Extraction may result in subsidence and low-level earthquakes.

Oil spills from a wide range of sources, including pipeline leaks and oil tanker spills, can contaminate soils. A large volume spill of petroleum can remain in the soil for a long time. A comprehensive review of remediation technologies for oil contaminated soil indicates that no single technique will be effective for all cases (Lim, Von Lau, and Poh 2016).

Solid waste produced by oil refineries include both hazardous and non-hazardous wastes, and separating the two can be an engineering challenge (Amiry, Sutherland, and Martin 1997). The waste may be incinerated (which further contributes to air pollution), landfilled, or deep well injected.

There have been several reviews of the vast literature of the degradation of petroleum and its derivatives (Zobell 1946; Atlas 1981; Das and Chandran 2011). Because of their complexity, petroleum and its fractions are difficult to generalize. Petroleum is insoluble and therefore does not degrade by hydrolysis. While the aromatic fractions are photodegradable, the aliphatic fractions—which would be the main constituents of PDSOs—are only photodegradable to a point. One review of petroleum spills found that while aliphatic petroleum fractions were reduced by photodegradation and branched structures became linear, short-chain aliphatic structures were stable when exposed to solar radiation (Nicodem et al. 1997). Because sunlight does not penetrate much below the soil surface, photodegradation is not a significant factor in the breakdown of environmental contaminants (McBride 1994). Historically, aliphatic fractions were considered biologically inert, but various soil organisms were observed to degrade paraffin as early as 1906 (Söhngen 1906; Zobell 1946). Because PDSOs do not degrade via hydrolysis or photolysis and are not readily biodegradable, petroleum spray oils are likely to remain in the environment. For the most part, they will adsorb to soil particles and not actually biodegrade (Cornish, Battersby, and Watkinson 1993).

The environmental fate and long-term ecological effects of large-scale petroleum releases into the aquatic and terrestrial environments have been studied extensively (Albers 1995; Albers 2007; Chang et al. 2014). Most field studies have been conducted in the wake of numerous accidental releases, such as oilfield gushers, off-shore platform blowouts, pipeline leaks, train tanker derailments, ocean tanker shipwrecks, and refinery explosions. These high-profile accidents account for less total petroleum released into the environment compared with the cumulative effects of continuous, incidental low-level losses, leaks, and seepage from wells, refineries, and storage facilities (Morgan and Watkinson 1989). Incidental releases are more widely distributed over time and space than accidental releases.

PDSOs are not the only source of use and misuse of petroleum products in the environment, with the main ones related to the improper storage and handling of petroleum-based hydrocarbons as fuels. The primary use of petroleum is gasoline, which accounted for about 47 percent of petroleum used in 2017 (US EIA 2018); about 84 percent of petroleum was used for gasoline and other fuels. PDSOs can be characterized as a relatively minor use of petroleum. A detailed analysis of the extensive literature on environmental contamination by all petroleum product releases into the environment is beyond the scope of this review.

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)).

PDSOs are generally non-reactive with the other substances used in organic crop production, such as lime-sulfur, sulfur, or botanicals. The longer chain structures tend to be stable and may adsorb to leaves or soil (US EPA 2007). However, mixtures with sulfur are known to damage plants (Cranshaw and Baxendale 2005).

__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)).**

PDSOs can interact with the agro-ecosystem in several different ways. Because PDSOs are biocidal to mites and insects, they can reduce the populations of these organisms. The effects of PDSOs on soil organisms can be expected to vary by species, soil type, temperatures, water, and gas exchange conditions. PDSOs' suffocating mode of action is non-selective; when released into the environment, it will smother aerobic organisms, reduce light, and modify habitats through altered pH, decreased dissolved oxygen, and decreased food availability (Albers 1995).

Scientific literature has extensively reviewed the impact of petroleum contamination on soil and soil microorganisms, petroleum's biological degradation, and the potential for its bioremediation (Atlas 1981; Morgan and Watkinson 1989; Leahy and Colwell 1990; Van Hamme, Singh, and Ward 2003; Varjani 2017). However, very few of these specifically refer to PDSOs; most are reviews of crude oil contamination, with some referring to heavy mineral oil, PAHs, or various petroleum fuel products. Crude petroleum appears to have a mixed effect on soil bacteria and fungi, favoring some species while suppressing others (Jensen 1975; Llanos and Kjøller 1976; Pinholt, Struwe, and Kjøller 1979; Atlas 1981; Morgan and Watkinson 1989; P.-W. G. Liu et al. 2011).

Early experiments examined the effect of petroleum on soil microbial ecology, with subsequent research focused on the selection of species and manipulation of ecological conditions for bioremediation of contaminated soils. Populations of most bacterial groups tend to increase in soil media treated with mineral oil and oily waste under laboratory conditions, although *Streptomyces* and spore-forming bacteria were observed to decrease (Jensen 1975). Similarly, for fungi, some species were completely absent following treatment with crude petroleum, several showed no difference from a no-treatment control, and some fungal species thrived on petroleum (Llanos and Kjøller 1976). Besides species selection, soil properties that influence biological activity on petroleum are temperature, pH, salinity, and soil structure (Atlas 1981; Morgan and Watkinson 1989; Van Hamme, Singh, and Ward 2003). Linear and branched alkane structures—the predominate hydrocarbons in PDSOs—are considered the most readily biodegradable of the petroleum fractions (Van Hamme, Singh, and Ward 2003). Increased organic matter in soil can slightly accelerate biodegradation of petroleum under certain conditions, but the differences are small and inconsistent (Sarkar et al. 2005).

The effect of spray oils on beneficial organisms seems to vary based on the mobility of the organism, its stage of development, and its ability to reinvade after the application (Davidson et al. 1991). There have been a few controlled studies examining survival of predators and parasites exposed to mineral oils alone in field conditions. Orange trees in Australia treated for red scale (*Aonidiella aurantii*) with a summer oil also saw a drop in the scale predator *Aphytis melinus* (Campbell 1975). The predators recovered faster with summer oil treatments, and their populations fully recovered after 8 days. By contrast, there were no predators at all in the malathion-treated trees until 16 days after treatment, and the population never fully recovered to the levels seen with the no-treatment control.

A Washington state study examined the relative survival of pests and their natural enemy complexes in apple orchards treated with PDSOs (Fernandez et al. 2005). PDSOs were used as ovicides for codling moth (*Cydia pomonella*) and leafroller (*Pandemis pyrusana*), and as foliar sprays for apple leafhopper (*Typhlocyba pomaria*), wooly apple aphid (*Eriosoma lanigerum*), European red mite (*Panonychus ulmi*), two-spotted spider mite (*Tetranychus urticae*), McDaniel spider mite (*Tetranychus mcdanieli*), and apple rust mite (*Aculus schlectendali*) and compared with an untreated control orchard. Aphid predator lacewing and syrphid fly populations were not significantly different between the treated and control orchards. Similarly, parasitism rates of leafhoppers by *Anagrus* and *Aphelopus* wasps were found not to be significantly different between the PDSO-treated and control orchards. However, the populations of the beneficial mite species western predatory mite (*Galendromus occidentalis*) and the stigmaeid predatory mite (*Zetzellia mali*) were suppressed at rates comparable to those of the pest mites (Fernandez et al. 2005).

A Florida study compared different pesticides—including PDSO—both for efficacy in controlling citrus leafminer and the survival of its natural enemy, the parasitic wasp *Ageniaspis citricola.* PDSO caused mortality for both species within one hour, with a higher death rate for citrus leafminer larvae (Villanueva-Jiménez and Hoy 1998). Within 24–48 hours, adults of both pest and parasitoid recovered, with a higher rate of parasitism in the surviving pest population. The authors concluded that PDSOs were compatible with integrated pest management (IPM) and biological control (Villanueva-Jiménez and Hoy 1998).

Narrow-range mineral oil was applied under laboratory conditions to soybean aphids (*Aphis glycines*) and that aphid's key predator, the multi-colored Asian lady beetle (*Harmonia axyridis*) at various life stages (Kraiss and Cullen 2008). The study found mineral oil to cause 100 percent mortality of the soybean aphids. Mineral oil was moderately toxic to the larval stages of the lady beetle, with 48.9 percent and 31.9 percent mortality for the first and third instars, respectively. Mineral oil was not toxic to either pupae or adult lady beetles (Kraiss and Cullen 2008).

Citrus trees treated with two different brands of mineral oil for two-spotted spider mite in Spain were compared with other treatments and a no-treatment control for their relative impacts on natural enemies (Urbaneja et al. 2008). Mineral oil was highly effective against the target pest, with results comparable to or better than acaricides with toxic modes of action. The mortality of the beneficial mite *Neoseiulus californicus* populations after one and three days was no different from the no-treatment control. By day six, beneficial mite mortality was higher than the no-treatment control, but lower than the other pesticides used. Mineral oil was also found to be non-toxic to the aphid parasitoid *Aphidius colemani* and the mealybug destroyer (*Cryptolaemus montrouzieri*), a predator related to lady beetles (Urbaneja et al. 2008).

Mineral oils appear to be non-toxic to pollinators. A study reviewed by EPA determined that the 48-hour acute contact toxicity of a petroleum distillate to honey bees (*Apis mellifera*) was greater than 25 µg/ai/bee, which was also the NOEL (Hoxter, Palmer, and Krueger 1999). PDSOs are rated as "low" for pesticide movement through the soil profile into the water table, and have an estimated average half-life of 10 days in soil (Vogue, Kerle, and Jenkins 1994). Researchers considered the impact of mineral oils on soil microorganisms to be minimal, given that the oils will readily bind to soil particles and not be biologically available (Cornish, Battersby, and Watkinson 1993).

The earliest descriptions of the use of PDSOs acknowledged that they can injure plants (Jones 1919; deOng, Knight, and Chamberlin 1927; P. J. Chapman, Pearce, and Avens 1943). Petroleum-contaminated soils are noted to have lower plant biomass than uncontaminated soils (Merkl, Schultze-Kraft, and Infante 2005). Development of commercial products required removal of aromatics and sulfur-bearing compounds to reduce the amount of damage to the crops (Volck 1929; Voorhees 1937; P. Chapman et al. 1962; J. Baker 1970). In general, lower molecular weights correlate with greater plant damage and systemic injury (J. Baker 1970). Thus, petroleum products with aromatic, naphthenic, and PAH structures have the greatest ecological impact when released in the ecosystem (Albers 1995). Highly refined PDSOs that have low levels of these structures will have a short-lived and limited impact by comparison.

Certain common soil bacteria are reported to metabolize and biodegrade petroleum fractions. *Pseudomonas oleovorans* appears to metabolize certain petroleum fractions as a carbon source (McKenna and Coon 1970). *Bacillus subtilis* and *Bacillus cereus*—as well as some species of soil fungi—are reported to degrade petroleum fractions (Pesticide Research Institute 2015). Various grasses and legumes may also be an effective means of removing petroleum hydrocarbons from the soil (Merkl, Schultze-Kraft, and Infante 2005; Gaskin, Soole, and Bentham 2008). Microorganisms that biodegrade petroleum are believed to be stimulated by root exudates.

<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)).

When released into the environment, mineral oils are moderately persistent and are partitioned into soils and suspended solids. The EPA regards aliphatic solvents as practically non-toxic to fish and birds (US EPA 2007). However, mineral oil is highly toxic to the model aquatic invertebrate, *Daphnia magna.* Mineral oil had a 48-hour half maximal effective concentration (EC_{50}) value for *D. magna* of 0.10 ppm, with a No Observed Effect Concentrate (NOEC) of 0.023 ppm ai (Drotter and Krueger 1999). On the other hand, the lethal concentration (LC_{50}) for *D. magna* varied widely based on the formulation and ranged from 0.2 mg/L to 14 mg/L (US EPA 2007). The most toxic formulations are no longer registered with EPA.

Oils applied to plants reduce respiration and transpiration, and may have systemic effects that injure growing foliage (J. Baker 1970). Mineral oils that contain significant amounts of aromatic and naphthenic structures are also less biodegradable than those that are more highly refined paraffinic oils.

<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)).

Mineral oil toxicity varies according to oil composition and how it is treated. The EPA concluded that when compared with other pesticides, aliphatic solvents are practically non-toxic. Highly refined white mineral oil has a long history of safe use (Nash et al. 1996). In assessing aggregated exposure through all sources, aliphatic solvents have a "virtually insignificant impact on human health" (US EPA 2007). EPA has exempted petroleum oils from the requirement of a tolerance [40 CFR 180.905(a)(1)].

Despite the longstanding conclusion of low or non-toxicity, there is a growing concern about the health effects from the ingestion of mineral oil hydrocarbons through direct use as a food additive as well as from multiple sources of environmental contamination (EFSA 2012). Specifically, mineral oils have been linked to lipogranulomas in human livers (Dincsoy, Weesner, and Macgee 1982), though the causality has been questioned (Nash et al. 1996). Exposure to mineral oil hydrocarbons in food is greater than was once expected, requiring dietary intake as a direct food additive to be reconsidered (Grob 2018).

The scientific literature on the oral ingestion of mineral oil has been reviewed extensively (Nash et al. 1996; Kimber and Carrillo 2016). Most of the ingestion of mineral oil is as a direct, secondary, and indirect food additive used in food processing. Relatively few studies have examined ingestion as a pesticide contaminant of food. The complex aliphatic chains are not easily metabolized and/or bioavailable. What little gets absorbed in the digestive process accumulates in the liver, spleen, lymph nodes, and body fat (Nash et al. 1996). Some fat-soluble contaminants may be incorporated in aliphatic hydrocarbons.

There was evidence of linked autoimmunity in mice with exposure to mineral oil; however, the subsequent studies failed to generate a dose-response curve or link the incidents in the rodent model to human health (Kimber and Carrillo 2016). Both the avenues of exposure and the causes of autoimmunity are not understood well enough to consider the evidence conclusive. The authors concluded that dietary exposure to mineral oils does not represent a health risk for the development of autoimmune disease, or the intuition or enhancement of autoimmune responses.

Dermal penetration of mineral oil was reviewed with other topically applied substances used in cosmetics. The data showed that only a small fraction of mineral oil reaches the deeper layer of skin, with no evidence that mineral oils are percutaneously absorbed with other ingredients (Petry et al. 2017).

EPA classifies aliphatic solvents as either practically non-toxic (Category IV) or slightly toxic (Category III) (US EPA 2007). Applicators may be at some inhalation risk when exposed to fine droplet size, such as would be produced by an air-blast sprayer. Labels usually advise against inhaling the mist. Repeated or prolonged exposure to petroleum distillates may result in adverse health effects (InChem 1982).

Environmental exposure to petroleum hydrocarbons is difficult to measure, and human exposure is difficult to predict because of their widespread use. It is hard to determine what portion of mineral hydrocarbon ingestion is caused by PDSOs, particularly since similar substances are applied in large quantities as inactive as well as active ingredients. One study found that grape seed oil had higher levels of paraffins of mineral oil, suggesting an environmental source of contamination (Fiorini et al. 2008). However, the study did not specifically mention pesticide applications as the source.

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

Vegetable oils are among the non-synthetic alternatives to suffocating oils (Davidson et al. 1991). Castor, corn, cottonseed, linseed, and soybean oils are all exempt from the requirement of EPA registration in the United States under section 25(b) of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). These active ingredients are considered to pose minimum risk to human health and the environment (Baker and Grant 2018). Canola, safflower, and sunflower oils have also been tested for efficacy against many of the target insects of petroleum spray oils. Vegetable oils fully degrade in the soil, while mineral oils will only partially degrade (Cornish, Battersby, and Watkinson 1993).

Castor, cottonseed, and linseed oils were compared with a PDSO for the control of various citrus pests, particularly red scale (*Chrysomphalus aurantii*) (DeOng et al. 1927). All the vegetable oils were more toxic to scale than PDSO, which had a fatal immersion time of 240–1,400 minutes. Cottonseed oil was the most effective with lethal immersion times of 14–1,400 minutes. Linseed oil had a fatal immersion time of 30–1,300 minutes. However, the vegetable oils were all more toxic to the citrus plants than PDSO (DeOng et al. 1927).

Early laboratory experiments compared the penetrating action of various contact insecticides, including vegetable and essential oils, with lubricating oils (Moore and Graham 1918). Vegetable oils had comparable penetrating actions with lubricating oils, or early PDSOs. Natural essential oils—including citronella oil—had greater penetrating effect on the trachea (Moore and Graham 1918).

Soybean oil adheres to leaf surfaces longer than PDSOs, even under conditions of heavy precipitation (Bondada et al. 2000), which may make soybean oil a more effective alternative than PDSOs for some conditions and applications. One study compared the efficacy of soybean oil with a PDSO for controlling terrapin scale (*Mesolecanium nigrofasciatum*), San Jose scale (*Quadraspidiotus perniciosus*) and European red mite (*Panonychus ulmi*) on apples and peaches. Fruit tree stems dipped in a 7.5 percent solution of degummed soybean oil for one second resulted in 93 percent mortality of terrapin scales (Pless et al. 1995). No red mites survived at a rate of either 5 percent or 7.5 percent soybean oil, making its efficacy comparable to petroleum oil. The same article reported field tests where one application of 2.5 percent petroleum oil or 5.0 percent soybean oil sprayed on apple trees killed over 95 percent of *Q. perniciosus* populations. One application of 5.0 percent soybean oil and 0.6 percent emulsifier killed 85 percent of *M. nigrofasciatum* populations, and two applications killed over 98 percent (Pless et al. 1995). Two applications of 2.5 percent soybean oil killed only 72 percent of the *Q. perniciosus* populations.

In another study, apple trees infested with *M. nigrofasciatum* were treated with 3 percent petroleum oil, and with 6 percent degummed soybean oil with 0.6 percent emulsifier (Latron B-1956). Both sprays significantly reduced the numbers of first- and second-generation crawlers by more than 90 percent over two seasons compared to the no-treatment control, and were not significantly different from each other (Hix et al. 1999).

Soybean oil showed comparable efficacy to PDSOs sprayed on apple trees in the summer at a rate of 1 percent reduced *P. ulmi* populations by 94 percent, a rate comparable to the efficacy of a petroleum oil (Moran et al. 2003). Higher rates of 4 percent and 6 percent did not result in any greater *P. ulmi* control but did result in significantly greater phytotoxicity.

Summer sprays of soybean oil were effective in reducing populations of two-spotted spider mites (*Tetranychus urticae*) on burning bush (*Euonymus alatus*) (Lancaster et al. 2002). *T. urticae* populations were reduced by between 97–99 percent by single sprays of 1, 2, or 3 percent degummed soybean oil emulsified with Latron B-1956 and diluted with water. The control was a water spray (Lancaster et al. 2002). Soybean oil at the 2 percent and 3 percent concentrations suppressed photosynthesis for a short time but were not phytotoxic. The same researchers conducted a second experiment involving 0.75, 1.0, or 1.5 percent degummed soybean oil, again with a water-only control. One application reduced the *T. urticae* population by more than 95 percent compared to a water control. A second application of 0.25–1.5 percent emulsified degummed soybean oil resulted in ≥ 93 percent control of *T. urticae* compared to the water control, but a third spray provided little additional control. Beneficial mites were not affected by a single spray of soybean oil. At concentrations ≤ 1.5 percent, a single application of soybean oil did not significantly reduce photosynthesis. The efficacy of soybean oil was comparable to PDSO against *T. urticae*, and both had similar effects on photosynthesis. In the first experiment, soybean oil was less phytotoxic and caused less defoliation of stressed plants than the PDSO. In the other two experiments, defoliation was not significantly different between the soybean oil- and PDSO-treated plants.

Castor oil and peanut oil each inhibited the hatching of sweet potato whitefly (*Bemisia tabaci*) eggs, with 19 percent of the eggs being viable (Fenigstein et al. 2001). The result was significantly better than cottonseed, soybean, and sunflower oils, and comparable to using peanut oil alone. The same study showed that a 3 percent solution of castor oil effectively reduced survival rates of larvae, with 7.9 percent survival for the first instar, 4.1 percent for the second instar, 14.0 percent for the third instar, and 19.0 percent for the fourth instar. Used against adults, 3 percent castor oil caused 3 percent mortality after 2 hours, and 75 percent mortality after 24 hours. Another study found that 10 percent cottonseed oil reduced *B. tabaci* larval populations by 99 percent (Butler, Coudriet, and Henneberry 1991).

Essential oils such as citronella, clove, lemongrass, thyme, rosemary, peppermint, and corn mint oils may be more effective and less damaging to plants as summer or foliar sprays in some cases (Regnault-Roger 1997; Isman and Miresmailli 2011).

Various polysaccharides derived from vegetable gums were compared with PDSOs for the control of citrus leafminer (G. Beattie, Liu, et al. 1995). PDSOs were unequivocally more effective than the polysaccharides at all life stages and on all target citrus pest species. However, a mixture of PDSOs and polysaccharide gum may have a synergistic effect.

Fish oils have also long been used as an alternative to PDSOs as dormant sprays in deciduous tree fruit (Kelley 1930; Sams and Deyton 2002). Fish oil is not registered as an insecticide, and it is mainly used in dormancy as an adjuvant with lime-sulfur or as a foliar fertilizer with kelp. The combination is somewhat effective for fruit thinning (McArtney et al. 2006; Yoder et al. 2009). Organic apple farmers in Washington State reported fish oil provided mixed results with control of codling moth and aphids (Granatstein 2003). Fish oil was found to be slightly less effective in controlling citrus leafminer compared with PDSOs, but the difference was not significant. Fish oil was found to reduce the survival of citrus leafminer adults, but was ineffective against immature leafminers (Villanueva-Jiménez and Hoy 1998). It was selective for the citrus leafminer predator *Ageniaspis citricola*, so fish oil would be compatible with a biological control program.

Biopesticides may also be used as alternatives to PDSOs. One study compared the use of a 2 percent horticultural oil with a 0.5 percent wetting agent (Silwet L-77) with the biopesticidal active ingredient *Chromobacterium subtsugae* (brand name Grandevo) for three orchid pests: *T. urticae*, the Phalaenopsis mite (*Tenuipalpus pacificus*) and the long-tailed mealybug (*Pseudococcus longispinus*). The horticultural oil/wetting agent combination caused mortality of at least 82 percent of all pest species, but also killed the beneficial mites *Metaseiulus occidentalis* and *Hemicheyletia wellsina*. By comparison, Grandevo had a comparable level of control for *T. pacificus*, failed to kill either of the other pests, and did not kill any of the beneficial mites (Ray and Hoy 2014).

Bacillus thuringiensis (*Bt*) is a natural alternative for the control of Lepidopteran insects. A study of sweet corn grown in New England compared mineral oil with corn oil, *Bt*, and the fungal entomopathogen *Beauveria bassiana* for the control of *Ostrinia nubilalis, Helicoverpa zea,* and *Spodoptera frugiperda.* The combination of corn oil and *Bt* provided the greatest and most consistent control of the three pests (Hazzard et al. 2003).

Another study conducted in Iran compared garlic oil-soap emulsion, a blend of plant extracts in emulsion, and *Bt* with mineral oil for citrus leafminer. The garlic oil-soap emulsion was the most effective, with 68 percent mortality, followed by the plant emulsion at 63 percent, with the two treatments not significantly different. With a larval mortality of 49 percent, *Bt* was a more effective larvicide than mineral oil (38 percent mortality) (Amiri-BeSheli 2008). Mineral oil was the least effective of the four treatments. However, the study noted mineral oil deterred egg laying and served as an ovicide, while *Bt* did not.

Other biopesticides sometimes used for target pests of PDSOs include baculoviruses and other pathogens that infect Lepidopteran pests (Moscardi 1999). Examples are the codling moth granulosis virus (CMGV) (Swezey et al. 2000) and the nuclear polyhedrosis viruses (NPV) of the beet armyworm (*Spodoptera exigua*) and corn earworm (*Helicoverpa zea*) (Kolodny-Hirsch et al. 1997; Farrar and Ridgway 2000). Baculoviruses face several problems that make formulation and commercialization difficult (Black et al. 1997), however, there is renewed interest in developing them (Szewczyk et al. 2006). These biocontrol agents are not applied at the dormant stage and are not seen as direct substitutes for PDSOs; they may be applied with PDSOs as adjuvants or co-active agents.

Kaolin clay (Surround), a non-synthetic mined material, has been found to protect apples from a wide range of pests (Thomas et al. 2004; Marko et al. 2008). Kaolin clay also reduces fungal disease pressure and heat stress in apples (Glenn et al. 2001; Thomas et al. 2004). When applied as a dormant dust to apples, kaolin clay resulted in fewer Oblique-banded leafroller (*Choristoneura rosaceana*) larvae hatching, lower larvae survival, and reduced egg laying by adult female moths (Knight et al. 2000).

The botanical insecticides neem and pyrethrum may also be used as alternatives to PDSOs for a number of pests (Buss and Park-Brown 2002; Zehnder et al. 2007; Daniels, Miles, and Murray 2013). The fungal derivative, spinosad, is also a broad-spectrum insecticide used for aphids, whiteflies, leafhoppers, thrips, and other pests (Delate et al. 2008; Peck and Merwin 2010; Caldwell et al. 2013). However, these insecticides are not considered substitutes for dormant sprays. Botanicals and spinosad are not necessarily less toxic to non-target organisms and may disrupt populations of beneficial organisms when used as a foliar spray. For example, neem oil was found to prevent adult lady beetles (*Coccinella undecimpunctata*) from emerging from their pupae, and partially suppressed the emergence of syrphids (*Eupeodes fumipennis*), both natural enemies of the green peach aphid (*Myzus persicae*) (Lowery and Isman 1995). Neem oil alone was also found to be less effective against citrus leafminer than a mix of neem oil and PDSO, and slightly reduced the adult survival of the leafminer parasitoid *A. citricola*. However, parasitism remained high in the neem oil treatment (Villanueva-Jiménez and Hoy 1998). Spinosad can also adversely impact natural enemy populations, particularly those of parasitic wasps (Williams, Valle, and Viñuela 2003; Ndakidemi, Mtei, and Ndakidemi 2016).

Vegetable oils have long been known to suppress various fungal plant diseases.. Castor, canola (rapeseed), cottonseed, olive, and peach seed oils were all found to have comparable control of powdery mildew of hops (*Sphaerotheca humuli*) to various PDSOs (Martin and Salmon 1931). Emulsified canola, corn, olive, safflower, soybean, and sunflower oils each showed over 95 percent control values for powdery mildew (*Sphaerotheca fusca*) on cucumber leaf surfaces in a greenhouse test, with canola oil being the most effective at a rate of 98.9 percent control of leaf surface areas (Jee et al. 2009). Soybean oil was less effective in controlling powdery mildews (*Oidium tuckeri* and *Uncinula necator*) and downy mildew (*Plasmopara viticola*) in grapes. More specifically, soybean oil applied to grapes had marginal control of the two species that cause powdery mildew in Ontario, and was ineffective against the downy mildew pathogen (Northover and Schneider 1996).

Reasons for PDSOs instead of vegetable oils seem to vary by crop, target organism, and region. For citrus, vegetable oils may results in higher phytotoxicity in some cases (DeOng, Knight, and Chamberlin 1927). The natural origin of plant and animal oils makes them more variable than PDSOs in their composition and quality (Bográn, Ludwig, and Metz 2006). While vegetable oil efficacy in experimental trials may be comparable or even superior, there is a perception that they perform less consistently than PDSOs under field conditions (Agnello 2002; Cranshaw and Baxendale 2005). Cost may also be a factor, depending on the relative prices of petroleum and vegetable oils.

Vegetable and fish oils may be formulated with synthetic emulsifiers or other inert ingredients. However, vegetable and fish oils without emulsifiers are widely available. Any non-synthetic oil used in organic production would need to meet the requirements for inert ingredients in 7 CFR 205.601(m), just as PDSOs would. The synthetic portion of such formulations would be in the range of 1-5%, instead of 100% as in the case of PDSOs. For minimum risk (FIFRA 25b) formulations, the inert ingredients would also need to be minimum risk and would be reported on the label. Inert ingredients in vegetable oils that are EPA registered would be confidential business information (CBI).

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

Increased biodiversity has been shown to reduce pest pressure in a wide range of agro-ecosystems (M. A. Altieri and Letourneau 1982; M. Altieri and Nicholls 2004; Zehnder et al. 2007; Vandermeer, Perfecto, and Philpott 2010). Crop rotation, inter-cropping, and permaculture designs offer possible cultural methods for reducing pest pressure overall in annual crops (Yepsen 1984; Mollison 1988; Holmgren 2002; Zehnder et al. 2007). For example, apple orchards intercropped with aromatic species such as peppermint (*Mentha canadensis*), ageratum (*Agerarum houstonianum*), French marigold (*Tagetes patula*), and basil (*Ocimum basilicum*) decreased herbivore abundance, increased predator populations, and shifted the arthropod community structure from being herbivore-dominated to being predator-dominated (Song et al. 2012). Aphid species in particular were significantly reduced by such intercropping. . Varietal choice, habitat management, and mass releases of beneficial organisms are all part of an overall strategy for organic apple orchard management (Swezey et al. 2000; M. Altieri and Nicholls 2004; Wyss et al. 2005). However, these guides do not preclude the use of PDSOs in conjunction with an integrated strategy that relies primarily on cultural practices. Increased biodiversity has been shown to reduce pest and disease pressure in orchard systems (Altieri, Davis, and Burroughs 1983; Simon et al. 2011). Native beneficial organisms including insects, spiders, and birds all help control pests in these systems.

Alternative cultural methods for managing aphids, mites, and other soft-bodied plant pests include releasing predators and parasites. Aphids, mealybugs, and whiteflies are favored prey of lady beetles (*Hippodamia convergens*) and other coccinellid predators (Obrycki and Kring 1998). However, these predators are limited in their effectiveness against adult scale. Lacewings (*Chrysoperla* spp.) can also be effective when released in vineyards for pests such as the grape leafhopper and grape mealybug. In two California vineyards, inundative lacewing releases reduced grape leafhopper populations by 33.6 percent in the first generation and 31.4 percent in the second generation. (Daane et al. 1996). Lacewings are also broad predators in apple orchards (Szentkirályi 2001). Natural enemies are generally active during the season when foliage is present in deciduous orchards and annual crops. While they may be an alternative to summer oils, these predators are not a practical alternative to dormant oils used on deciduous perennials. Lacewings show distinct seasonality with their predation (Szentkirályi 2001).

The nematode *Steinernema carpocapsae* was found to provide comparable control of citrus leafminer to PDSOs in Australia (Beattie, Somsook, et al. 1995). High rates of release of the beneficial nematodes performed better than the highest application rate for PDSOs. However, the nematode's cost of control at those rates was considered commercially unacceptable to citrus producers.

It is unclear whether dormant oils enable natural enemies to be more effective during the growing season by reducing the target pest population, or if their ovicidal activity reduces the populations of natural enemies as well as pests (Davidson et al. 1991). The two may be complimentary strategies, with releases to restore beneficial organism populations a few days following a knock-down spray with PDSOs. Commercial delivery of live beneficial organisms is a practical option, but it can present challenges (Tauber et al. 2000).

Predator and parasitoid populations can be enhanced by planting and maintaining habitat plants that provide shelter and food throughout their life-cycles. Again, PDSOs are compatible with managed habitat and are not an "either/or" alternative.

Since the energy crisis of the 1970s and the on-set of peak oil, there is a recognition that agriculture needs to develop sustainable alternatives to petroleum (Rosset and Altieri 1997; Youngquist 1999; Peters et al. 2009). Research has focused on developing sustainable alternative fuels for mechanized farm equipment and transportation of food to market. However, the analyses also recognize the need to replace petrochemical inputs with agroecological techniques (Rosset and Altieri 1997).

Report Authorship

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

- Brian Baker, Consultant, Organic Materials Review Institute
- Tina Jensen Augustine, Senior Bilingual Technical Coordinator, Organic Materials Review Institute
- Lindsay Kishter, Director, Nexight Group
- Rachel Lanspa, Communications Associate, Nexight Group

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

References

Ackerson, M.D., Arabshahi, S., and Babcock, R.E. 1993. Process for petroleum-wax separation at or above room temperature. 5,196,116, issued March 23, 1993.
Agnello, A.M. 2002. "Petroleum-Derived Spray Oils: Chemistry, History, Refining and Formulation." In *Spray Oils beyond 2000*, edited by Beattie, G.A.C., Watson, D.M., Stevens, M.L., Rae, D.J., and Spooner-Hart, R.N., 2–18. Sydney, Australia: University of Western Sydney.
Albers, P.H. 1995. "Petroleum and Individual Polycyclic Aromatic Hydrocarbons." In *Handbook of Ecotoxicology*, edited by Hoffman, D.J., Rattner, B.A., Burton, G.A. Jr., and Cairns, J. Jr. 2nd ed., 342–71. Boca Raton, FL: CRC.
———. 2007. *An Annotated Bibliography on Petroleum Pollution*. Beltsville, MD: USGS Patuxent Wildlife Research Center. https://pdfs.semanticscholar.org/53db/c5acee541057786f085c0a3a0411414200a6.pdf.
Allen, L., Cohen, M.J., Abelson, D., and Miller, B. 2012. "Fossil Fuels and Water Quality." In *The World's Water*, edited by Gleick, P.H. 73–96. Springer.
Allison, E., and Mandler, B. 2018. "Petroleum and the Environment: An Introduction." Alexandria, VA: American Geosciences Institute. https://www.americangeosciences.org/critical-issues/factsheet/pe/petroleum-environment-introduction.
Altieri, M.A., Davis, J., and Burroughs, K. 1983. "Some Agroecological and Socio-Economic Features of Organic Farming in California. A Preliminary Study." *Biological Agriculture & Horticulture* 1 (2): 97–107.
Altieri, M.A., and Letourneau, D.K. 1982. "Vegetation Management and Biological Control in Agroecosystems." *Crop Protection* 1 (4): 405–430.
Altieri, M., and Nicholls, C. 2004. *Biodiversity and Pest Management in Agroecosystems*. CRC Press.

Amiri-BeSheli, B. 2008. "Efficacy of *Bacillus Thuringiensis*, Mineral Oil, Insecticidal Emulsion and Insecticidal Gel against *Phyllocnistis Citrella* Stainton (Lepidoptera: Gracillariidae)." *Plant Protection Science* 44 (2): 68–73.

Amiry, H., Sutherland, H., and Martin, E. 1997. "Environmental Management and Technology in Oil Refineries." In *Environmental Technology in the Oil Industry*, edited by Orszulik, S.T., 291–329. Hampshire, UK: Springer.

ASTM. 2018. "Petroleum Standards." 2018. https://www.astm.org/Standard/interests/petroleum-standards.html.

Atlas, R.M. 1981. "Microbial Degradation of Petroleum Hydrocarbons: An Environmental Perspective." *Microbiological Reviews* 45 (1): 180–209.

Baker, B.P., and Grant, J.A. 2018. "Active Ingredients Eligible for Minimum Risk Pesticide Use." Geneva, NY: New York State IPM Program. https://nysipm.cornell.edu/environment/active-ingredients-eligible-minimum-risk-pesticide-use/.

Baker, J.M. 1970. "The Effects of Oils on Plants." *Environmental Pollution* 1 (1): 27–44.

Barker, C., Robbins, W.K., Hsu, C.S., and Drew, L.J. 2007. "Petroleum." *Kirk-Othmer Concise Encyclopedia of Chemical Technology*. Hoboken, NY: Wiley.

Beattie, G.A.C., Clift, A.D., Allender, W.J., Jiang, L., and Wang, Y.A. 1991. "Efficacies of Low-to High-Volume (960-10 700 Litre Ha- 1) Citrus Sprayers for Applying Petroleum Spray Oil to Control Chinese Wax Scale." *Pesticide Science* 32 (1): 47–56.

Beattie, G.A.C., Liu, Z.M., Watson, D.M., Clift, A.D., and Jiang, L. 1995. "Evaluation of Petroleum Spray Oils and Polysaccharides for Control of *Phyllocnistis Citrella* Stainton (Lepidoptera: Gracillariidae)." *Australian Journal of Entomology* 34 (4): 349–353.

Beattie, G.A.C., Somsook, V., Watson, D.M., Clift, A.D., and Jiang, L. 1995. "Field Evaluation of *Steinernema Carpocapsae* (Weiser)(Rhabditida: Steinernematidae) and Selected Pesticides and Enhancers for Control of *Phyllocnistis Citrella* Stainton (Lepidoptera: Gracillariidae)." *Australian Journal of Entomology* 34 (4): 335–342.

Black, B.C., Brennan, L.A., Dierks, P.M., and Gard, I.E. 1997. "Commercialization of Baculoviral Insecticides." In *The Baculoviruses*, edited by Miller, L., 341–387. New York: Springer.

Bográn, C.E., Ludwig, S., and Metz, B. 2006. "Using Oils as Pesticides." Extension publication E-419. College Station, TX: Texas A&M.

Bondada, B.R., Sams, C.E., Deyton, D.E., and Cummins, J.C. 2000. "Apple and Peach Leaf and Stem Surface Morphology and Soybean Oil Retention as Influenced by Simulated Rainfall and Soybean Oil Emulsions." *Journal of the American Society for Horticultural Science* 125 (5): 553–557.

Buss, E.A., and Park-Brown, S.G. 2002. "Natural Products for Insect Pest Management." *UF/IFAS Publication ENY-350.* http://edis.ifas.ufl.edu/IN197.

Buteler, M., and Stadler, T. 2011. "A Review on the Mode of Action and Current Use of Petroleum Distilled Spray Oils." In *Pesticides in the Modern World-Pesticides Use and Management*. InTech.

Butler, G.D., Coudriet, D.L., and Henneberry, T.J. 1991. "Effect of Plant-Derived Oils on Sweetpotato Whitefly on Cotton." Cotton: A College of Agriculture Report. Tucson, AZ: University of Arizona.

Caldwell, B., Sideman, E., Seaman, A., Shelton, A., and Smart, C. 2013. *Resource Guide for Organic Insect and Disease Management.* Cornell University, Ithaca, NY. Geneva, NY: New York State Agricultural Experiment Station.

Cal-EPA. 2018. "Chemicals Known to the State to Cause Cancer or Reproductive Toxicity." Sacramento, CA: Cal-EPA. https://oehha.ca.gov/media/downloads/crnr/p65list052518.pdf.

Campbell, M.M. 1975. "Duration of Toxicity of Residues of Malathion and Spray Oil on Citrus Foliage in South Australia to Adults of a California Red Scale Parasite *Aphytis Melinus* DeBach (Hymenoptera: Aphelinidae)." *Australian Journal of Entomology* 14 (2): 161–164.

CAN/CGSB. 2015. *Organic Production Systems: Permitted Substances List*. 32.311-2015. Ottawa, ON, Canada: Canadian General Standards Board. http://www.tpsgc-pwgsc.gc.ca/ongc-cgsb/programme-program/normes-standards/internet/bio-org/lsp-psl-eng.html.

Chaineau, C.H., Rougeux, G., Yepremian, C., and Oudot, J. 2005. "Effects of Nutrient Concentration on the Biodegradation of Crude Oil and Associated Microbial Populations in the Soil." *Soil Biology and Biochemistry* 37 (8): 1490–1497.

Chang, S.E., Stone, J., Demes, K., and Piscitelli, M. 2014. "Consequences of Oil Spills: A Review and Framework for Informing Planning." *Ecology and Society* 19 (2).

Chapman, P.J., Pearce, G.W., and Avens, A.W. 1943. "Relation of Composition to the Efficiency of Foliage or Summer Type Petroleum Fractions1, 2, 3." *Journal of Economic Entomology* 36 (2): 241–47. https://doi.org/10.1093/jee/36.2.241.

Chapman, P.J. 1967. "Petroleum Oils for the Control of Orchard Pests." Extension Bulletin 814. Ithaca, NY: Cornell University.

Chapman, P.J., Lienk, S.E., Avens, A.W., and White, R.W. 1962. "Selection of a Plant Spray Oil Combining Full Pesticidal Efficiency with Minimum Plant Injury Hazards." *Journal of Economic Entomology* 55 (5): 737–744.

Chin, P., and Stewart, J. 1994. "Mineral Oil – Review of Acute Toxicity Studies." 416853–07 to 416853–10. Washington DC: U.S. EPA. https://www3.epa.gov/pesticides/chem_search/cleared_reviews/csr_PC-063502_3-Mar-94_006.pdf.

Cooper, J.E. 1977. Oil recovery method employing acids extracted from crudes using an ion-exchange process. U.S. Patent Office 4,037,656, issued July 26, 1977.

Cornish, A., Battersby, N.S., and Watkinson, R.J. 1993. "Environmental Fate of Mineral, Vegetable and Transesterified Vegetable Oils." *Pesticide Science* 37 (2): 173–178.

Cranshaw, W.S., and Baxendale, B. 2005. "Insect Control: Horticultural Oils." Home & Garden Extension 5.569. Insect Series. Ft Collins, CO: Colorado State University.

Daane, K.M., Yokota, G.Y., Zheng, Y., and Hagen, K.S. 1996. "Inundative Release of Common Green Lacewings (Neuroptera: Chrysopidae) to Suppress *Erythroneura Variabilis* and *E. Elegantula* (Homoptera: Cicadellidae) in Vineyards." *Environmental Entomology* 25 (5): 1224–1234.

Daniels, C.H., Miles, C.A., and Murray, T.A. 2013. "Natural Insecticides." PNW649. Pacific Northwest Extension Publication. Pullman, WA: Washington State University. https://research.wsulibs.wsu.edu/xmlui/bitstream/handle/2376/4615/PNW649.pdf?sequence=2.

Das, N., and Chandran, P. 2011. "Microbial Degradation of Petroleum Hydrocarbon Contaminants: An Overview." *Biotechnology Research International* 2011.

Davidson, N.A., Dibble, J.E., Flint, M.L., Marer, P.J., and Guye, A. 1991. "Managing Insects and Mites with Spray Oils." 3347. IPM Education and Publications, Statewide Integrated Pest Management Project,. Oakland, CA: University of California, Division of Agriculture and Natural Resources.

Decroocq, D. 1984. *Catalytic Cracking of Heavy Petroleum Fractions*. Paris, FR: Editions Technip.

Delate, K., McKern, A., Turnbull, R., Walker, J.T.S., Volz, R., White, A., Bus, V., et al. 2008. "Organic Apple Production in Two Humid Regions: Comparing Progress in Pest Management Strategies in Iowa and New Zealand." *HortScience* 43 (1): 12–21.

deOng, E.R. 1948. *Chemistry and Uses of Insecticides*. New York, NY: Reinhold.

deOng, E.R., Knight, H., and Chamberlin, J.C. 1927. "A Preliminary Study of Petroleum Oil as an Insecticide for Citrus Trees." *Hilgardia* 2 (9): 351–384. https://doi.org/DOI:10.3733/hilg.v02n09p351.

Dincsoy, H.P., Weesner, R.E., and Macgee, J. 1982. "Lipogranulomas in Non-Fatty Human Livers: A Mineral Oil Induced Environmental Disease." *American Journal of Clinical Pathology* 78 (1): 35–41.

Drotter, K.R., and Krueger, H.O. 1999. "Acute EC50 Test with a Freshwater Invertebrate." Data Evaluation Record 447693–01. Washington DC: U.S. EPA. https://www3.epa.gov/pesticides/chem_search/cleared_reviews/csr_PC-063502_4-Jun-99_014.pdf.

EFSA. 2012. "Scientific Opinion on Mineral Oil Hydrocarbons in Food." *EFSA Journal* 10 (6): 2704.

EPI. 2012. "Estimation Programs Interface (EPI) Suite (V4.11)." Washington, DC: U.S. EPA Office of Pesticides and Toxic Substances.

Erler, F. 2004. "Oviposition Deterrency and Deterrent Stability of Some Oily Substances against the Pear PsyllaCacopsylla Pyri." *Phytoparasitica* 32 (5): 479–485.

EU Commission. 2008. *Organic Production and Labelling of Organic Products with Regard to Organic Production, Labelling and Control. EC.* Vol. 889/2008. https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:250:0001:0084:EN:PDF.

Fahim, M.A., Al-Sahhaf, T.A., and Elkilani, A. 2009. *Fundamentals of Petroleum Refining*. Elsevier.

FAO/WHO Joint Standards Programme. 1999. *Codex Alimentarius Guidelines for the Production, Processing, Labelling and Marketing of Organic Processed Foods*. CAC/GL 32-1999. Rome, IT & Geneva, CH: FAO/WHO. http://www.fao.org/organicag/doc/glorganicfinal.pdf.

Farrar, R.R., and Ridgway, R.L. 2000. "Host Plant Effects on the Activity of Selected Nuclear Polyhedrosis Viruses against the Corn Earworm and Beet Armyworm (Lepidoptera: Noctuidae)." *Environmental Entomology* 29 (1): 108–115.

FDA. 2000. "Agency Response Letter GRAS Notice No. GRN 000040," December 11, 2000.

———. 2001. "Agency Response Letter GRAS Notice No. GRN 000071," April 20, 2001.

Fenigstein, A., Eliyahu, M., Gan-Mor, S., and Veierov, D. 2001. "Effects of Five Vegetable Oils on the Sweetpotato Whitefly Bemisia Tabaci." *Phytoparasitica* 29 (Copyright (C) 2015 American Chemical Society (ACS). All Rights Reserved.): 197–206. https://doi.org/10.1007/BF02983451.

Fernandez, D.E., Beers, E.H., Brunner, J.F., Doerr, M.D., and Dunley, J.E. 2005. "Effects of Seasonal Mineral Oil Applications on the Pest and Natural Enemy Complexes of Apple." *Journal of Economic Entomology* 98 (5): 1630–1640.

Fiorini, D., Fiselier, K., Biedermann, M., Ballini, R., Coni, E., and Grob, K. 2008. "Contamination of Grape Seed Oil with Mineral Oil Paraffins." *Journal of Agricultural and Food Chemistry* 56 (23): 11245–11250.

Gallagher, S.P., Grimes, J., and Beavers, J.B. 1998. "Avian Single Dose LD50 Test for Mineral Oil." Data Evaluation Record 446080–01. Washington DC: U.S. EPA. https://www3.epa.gov/pesticides/chem_search/cleared_reviews/csr_PC-063502_6-Oct-98_008.pdf.

———. 1999a. "Upland Game Bird Dietary LC50 Test for Petroleum Distillates." Data Evaluation Record 481–102. Washington DC: U.S. EPA. https://www3.epa.gov/pesticides/chem_search/cleared_reviews/csr_PC-063502_4-Jun-99_015.pdf.

———. 1999b. "Waterfowl Dietary LC50 Test for Petroleum Distillates." Data Evaluation Record 481–103. Washington DC: U.S. EPA. https://www3.epa.gov/pesticides/chem_search/cleared_reviews/csr_PC-063502_4-Jun-99_015.pdf.

Gaskin, S., Soole, K., and Bentham, R. 2008. "Screening of Australian Native Grasses for Rhizoremediation of Aliphatic Hydrocarbon-Contaminated Soil." *International Journal of Phytoremediation* 10 (5): 378–389.

Glenn, D. M., van der Zwet, T., Puterka, G.J., Gundrum, P., and Brown, E. 2001. "Efficacy of Kaolin-Based Particle Films to Control Apple Diseases." *Plant Health Prog* 23.

Grafton-Cardwell, E.E., Morse, J.G., O'Connell, N.V., Phillips, P.A., Kallsen, C.E., and Haviland, D.R. 2008. "UC IPM Pest Management Guidelines: Citrus UC ANR Publication 3441." Oakland, CA: University of California, Division of Agriculture and Natural Resources.

Granatstein, D. 2003. "Tree Fruit Production with Organic Farming Methods." *Wenatchee (WA) Center for Sustainable Agriculture and Natural Resources,* Washington State University. http://organic.rfrec.wsu.edu/OrganicIFP/OrganicFruitProduction/OrganicMgt.pdf.

Grob, K. 2018. "Mineral Oil Hydrocarbons in Food: A Review." *Food Additives & Contaminants: Part A* 35 (9): 1845–60. https://doi.org/10.1080/19440049.2018.1488185.

Haus, F., German, J, and Junter, G. 2001. "Primary Biodegradability of Mineral Base Oils in Relation to Their Chemical and Physical Characteristics." *Chemosphere* 45 (6): 983–90. https://doi.org/10.1016/S0045-6535(01)00027-3.

Hazzard, R.V., Schultz, B.B., Groden, E., Ngollo, E.D., and Seidlecki, E. 2003. "Evaluation of Oils and Microbial Pathogens for Control of Lepidopteran Pests of Sweet Corn in New England." *Journal of Economic Entomology* 96 (6): 1653–1661.

Herron, G.A., Beattie, G.A.C., Kallianpur, A., and Barchia, I. 1998. "Influence of Spray Volume and Oil Concentration on the Efficacy of Petroleum Spray Oil against Myzus Persicae (Sulzer)(Hemiptera: Aphididae)." *Australian Journal of Entomology* 37 (1): 70–73.

Herron, G.A., Beattie, G.A.C., Parkes, R.A., and Barchia, I. 1995. "Potter Spray Tower Bioassay of Selected Citrus Pests to Petroleum Spray Oil." *Australian Journal of Entomology* 34 (3): 255–263.

Hix, R.L., Pless, C.D., Deyton, D.E., and Sams, C.E. 1999. "Management of San Jose Scale on Apple with Soybean-Oil Dormant Sprays." *HortScience* 34 (1): 106–108.

Holmgren, D. 2002. *Permaculture: Principles & Pathways beyond Sustanability*. Hepburn, Australia: Holmgren Design Services,.

Hoxter, K.A., Palmer, S.J., and Krueger, H.O. 1999. "Honey Bee Contact LD50 Test: Petroleum Distillate." 446833–01. Washington DC: U.S. EPA. https://www3.epa.gov/pesticides/chem_search/cleared_reviews/csr_PC-063502_1-Feb-99_011.pdf.

HSDB. 2015. "National Library of Medicine Hazardous Substances Data Bank (HSDB)." 2015. http://toxnet.nlm.nih.gov/newtoxnet/hsdb.htm.

IARC. 2012. "Mineral Oils." 100F. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. Lyon, FR: International Agency for Research on Cancer. https://monographs.iarc.fr/wp-content/uploads/2018/06/mono100F.pdf.

IFOAM. 2014. *IFOAM Norms*. Bonn, Germany: IFOAM. https://www.ifoam.bio/en/ifoam-norms.

InChem. 1982. "Selected Petroleum Products." 20. Environmental Health Criteria. Geneva, CH: WHO.

Isman, M.B., and Miresmailli, S. 2011. "Plant Essential Oils as Repellents and Deterrents to Agricultural Pests." In *Recent Developments in Invertebrate Repellents*, edited by Paluch, G.E. and Coats, J.R, 1090:67–77. ACS Symposium Series. ACS, Div Chem Educ; ACS, Div Ind & Engn Chem; ACS, Div Fuel Chem.

Jacques, D.F., and Kuhlmann, B. 2002. "ExxonMobil Experience with Horticultural Mineral Oil." In *Spray Oils beyond 2000*, 39–51. Sydney, Australia: University of Western Sydney.

Japan MAFF. 2000. *Japanese Agricultural Standard for Organic Plants. Japanese Agricultural Standard*. Vol. 59. http://www.maff.go.jp/e/policies/standard/jas/specific/attach/pdf/criteria_o-1.pdf.

Jee, H., Shim, C., Ryu, K., Park, J., Lee, B., Choi, D., and Ryu, G. 2009. "Control of Powdery and Downy Mildews of Cucumber by Using Cooking Oils and Yolk Mixture." *The Plant Pathology Journal* 25 (3): 280–285.

Jensen, V. 1975. "Bacterial Flora of Soil after Application of Oily Waste." *Oikos* 26 (2): 152–158.

Johnson, W.T. 1994. "Oils as Pesticides for Ornamental Plants." In *Handbook of Integrated Pest Management for Turf and Ornamentals*, edited by Leslie, A.R., 557–581. Boca Raton, FL: CRC.

Jones, P.R. 1919. Combined insecticide and fungicide. U.S. Patent Office 1,291,013, issued January 14, 1919.

Kelley, V.W. 1930. "Effect of Certain Hydrocarbon Oils on Respiration of Foliage and Dormant Twigs of the Apple." Bulletin 348. Urbana, IL: University of Illinois, Urbana-Champaign campus, Agricultural Experiment Station.

Kimber, I., and Carrillo, J. 2016. "Oral Exposure to Mineral Oils: Is There an Association with Immune Perturbation and Autoimmunity?" *Toxicology* 344–346 (February): 19–25. https://doi.org/10.1016/j.tox.2016.01.008.

Knight, A.L., Unruh, T.R., Christianson, B.A., Puterka, G.J., and Glenn, D.M. 2000. "Effects of a Kaolin-Based Particle Film on Obliquebanded Leafroller (Lepidoptera: Tortricidae)." *Journal of Economic Entomology* 93 (3): 744–749.

Kolodny-Hirsch, D.M., Sitchawat, T., Jansiri, T., Chenrchaivachirakul, A., and Ketunuti, U. 1997. "Field Evaluation of a Commercial Formulation of the *Spodoptera Exigua* (Lepidoptera: Noctuidae) Nuclear Polyhedrosis Virus for Control of Beet Armyworm on Vegetable Crops in Thailand." *Biocontrol Science and Technology* 7 (4): 475–488.

Kraiss, H., and Cullen, E.M. 2008. "Efficacy and Nontarget Effects of Reduced-Risk Insecticides on Aphis Glycines (Hemiptera: Aphididae) and Its Biological Control Agent Harmonia Axyridis (Coleoptera: Coccinellidae)." *Journal of Economic Entomology* 101 (2): 391–398.

Kumar, V., Avery, P.B., Ahmed, J., Cave, R.D., McKenzie, C.L., and Osborne, L.S. 2017. "Compatibility and Efficacy of Isaria Fumosorosea with Horticultural Oils for Mitigation of the Asian Citrus Psyllid, Diaphorina Citri (Hemiptera: Liviidae)." *Insects* 8 (4): 119.

Lancaster, A.L., Deyton, D.E., Sams, C.E., Cummins, J.C., Pless, C.D., and Fare, D.C. 2002. "Soybean Oil Controls Two-Spotted Spider Mites on Burning Bush." *Journal of Environmental Horticulture* 20 (2): 86–92.

Larew, H.G. 1988. "Effects of 4 Horticultural Oils on Whitefly Oviposition, 1987." *Insecticide and Acaricide Tests* 13 (1): 347.

Leahy, J.G., and Colwell, R.R. 1990. "Microbial Degradation of Hydrocarbons in the Environment." *Microbiological Reviews* 54 (3): 305–315.

Leong, S.C.T., Abang, F., Beattie, A., Kueh, R.J.H, and Wong, S.K. 2012. "Impacts of Horticultural Mineral Oils and Two Insecticide Practices on Population Fluctuation of *Diaphorina citri* and Spread of Huanglongbing in a Citrus Orchard in Sarawak." *The Scientific World Journal* 2012.

Lim, M.W., Lau, E.V., and Poh, P.E. 2016. "A Comprehensive Guide of Remediation Technologies for Oil Contaminated Soil—Present Works and Future Directions." *Marine Pollution Bulletin* 109 (1): 14–45.

Liu, P.G., Chang, T.C., Whang, L., Kao, C., Pan, P., and Cheng, S. 2011. "Bioremediation of Petroleum Hydrocarbon Contaminated Soil: Effects of Strategies and Microbial Community Shift." *International Biodeterioration & Biodegradation* 65 (8): 1119–1127.

Liu, Z.M., Beattie, G.A.C., Hodgkinson, M., Rose, H.A., and Jiang, L. 2001. "Influence of Petroleum-Derived Spray Oil Aromaticity, Equivalent n-Paraffin Carbon Number and Emulsifier Concentration on Oviposition by Citrus Leafminer, *Phyllocnistis Citrella* Stainton (Lepidoptera: Gracillariidae)." *Australian Journal of Entomology* 40 (2): 193–197.

Llanos, C., and Kjøller, A. 1976. "Changes in the Flora of Soil Fungi Following Oil Waste Application." *Oikos* 27 (3): 377–382.

Long, R.D., Foster, J., Hoxter, K.A., and Smith, G.J. 1990. "Neutral Oil: A Dietary LC50 Study with the Northern Bobwhite." Data Evaluation Record 481–102. Washington DC: U.S. EPA. https://www3.epa.gov/pesticides/chem_search/cleared_reviews/csr_PC-063502_18-Jan-94_003.pdf.

Lowery, D.T., and Isman, M.B. 1995. "Toxicity of Neem to Natural Enemies of Aphids." *Phytoparasitica* 23 (4): 297–306.

Lyman, A.L. 1939. Parasiticidal spray oil composition. U.S. Patent Office 2,166,500, issued July 18, 1939.

Marko, V., Blommers, L.H.M., Bogya, S., and Helsen, H. 2008. "Kaolin Particle Films Suppress Many Apple Pests, Disrupt Natural Enemies and Promote Woolly Apple Aphid." *Journal of Applied Entomology* 132 (1): 26–35.

Martin, H., and E. S. Salmon. 1931. "The Fungicidal Properties of Certain Spray Fluids. VIII. The Fungicidal Properties of Mineral, Tar and Vegetable Oils." *Journal of the Agricultural Society of the University College of Wales* 21 (Copyright (C) 2015 American Chemical Society (ACS). All Rights Reserved.): 638–58.

Mason, A.F. 1928. *Spraying, Dusting and Fumigating of Plants. A Popular Handbook on Crop Protection.* New York, NY: MacMillan.

Matsumura, F. 1975. *Toxicology of Insecticides*. 1st ed. New York, NY: Plenum.

McArtney, S., Palmer, J., Davies, S., and Seymour, S. 2006. "Effects of Lime Sulfur and Fish Oil on Pollen Tube Growth, Leaf Photosynthesis and Fruit Set in Apple." *HortScience* 41 (2): 357–360.

McBride, M.B. 1994. *Environmental Chemistry of Soils*. Oxford, UK: Oxford University Press.

McKenna, E.J, and Coon, M.J. 1970. "Enzymatic Omega-Oxidation IV. Purification and Properties of the Omega-Hydroxylase of Pseudomonas Oleovorans." *Journal of Biological Chemistry* 245 (15): 3882–3889.

Merkl, N., Schultze-Kraft, R., and Infante, C. 2005. "Assessment of Tropical Grasses and Legumes for Phytoremediation of Petroleum-Contaminated Soils." *Water, Air, and Soil Pollution* 165 (1–4): 195–209.

Mollison, B. 1988. *Permaculture: A Designer's Manual*. Tasmania, Australia: Tagari.

Moore, W., and Graham, S.A., 1918. "Physical Properties Governing the Efficacy of Contact Insecticides." *Journal of Agricultural Research* 13 (11).

Moran, R.E., Deyton, D.E., Sams, C.E., Pless, C.D., and Cummins, J.C. 2003. "Soybean Oil as a Summer Spray for Apple: European Red Mite Control, Net CO2 Assimilation, and Phytotoxicity." *HortScience* 38 (2): 234–238.

Morgan, P., and Watkinson, R.J. 1989. "Hydrocarbon Degradation in Soils and Methods for Soil Biotreatment." *Critical Reviews in Biotechnology* 8 (4): 305–33. https://doi.org/10.3109/07388558909148196.

Moscardi, F. 1999. "Assessment of the Application of Baculoviruses for Control of Lepidoptera." *Annual Review of Entomology* 44 (1): 257–289.

Nash, J.F., Gettings, S.D., Diembeck, W., Chudowski, M., and Kraus, A.L. 1996. "A Toxicological Review of Topical Exposure to White Mineral Oils." *Food and Chemical Toxicology* 34 (2): 213–225.

Ndakidemi, B., Mtei, K., and Ndakidemi, P.A. 2016. "Impacts of Synthetic and Botanical Pesticides on Beneficial Insects." *Agricultural Sciences* 7 (06): 364.

Neumann, H., Paczynska-Lahme, B., and Severin, D. 1981. *Composition and Properties of Petroleum*. Vol. 5. Geology of Petroleum. Stuttgart, Germany: Enke.

Neumann, H., and Rahimian, I. 1984. *Petroleum Refining*. Vol. 7. Geology of Petroleum. Stuttgart, Germany: Enke.

Nicodem, D.E., Guedes, C.L., Correa, R.J., and Fernandes, M.C.Z. 1997. "Photochemical Processes and the Environmental Impact of Petroleum Spills." *Biogeochemistry* 39 (2): 121–138.

NIOSH. 2003. "Registry of Toxic Effects of Chemical Substances (RTECS): Mineral Oil." PY8030000. Atlanta, GA: Centers for Disease Control. https://www.cdc.gov/niosh-rtecs/PY7A8730.html.

Northover, J., and Schneider, K.E. 1996. "Physical Modes of Action of Petroleum and Plant Oils on Powdery and Downy Mildews of Grapevines." *Plant Disease* 80 (5): 544–550.

NOSB. 1995. "National Organic Standards Board Meeting Minutes, Orlando, Florida, April 24-28, 1995." Orlando, FL: USDA/AMS/NOSB.

———. 2002. "National Organic Standards Board Meeting Minutes, Washington, DC September 17-19, 2002." Washington, DC: USDA/AMS/NOSB.

NYS DEC. 2015. "Final Supplemental Generic Environmental Impact Statement on the Oil, Gas, and Solution Mining Regulatory Program." Albany, NY: NY State Department of Environmental Conservation. https://www.dec.ny.gov/docs/materials_minerals_pdf/findingstatehvhf62015.pdf.

Obrycki, J.J, and Kring, T.J. 1998. "Predaceous Coccinellidae in Biological Control." *Annual Review of Entomology* 43 (1): 295–321.

Ouyang, G., Fang, X., Lu, H., Zhou, X., Meng, X, Yu, S., Guo, M., and Xia, Y. 2013. "Repellency of Five Mineral Oils against *Diaphorina Citri* (Hemiptera: Liviidae)." *Florida Entomologist*, 974–982.

Parkash, S. 2003. *Refining Processes Handbook*. Amsterdam; Boston: Gulf Professional Pub.

Peck, G., and Merwin, I.A. 2010. "A Grower's Guide to Organic Apples." NYS IPM Publication 223. Geneva, NY: New York State IPM Program.

Pesticide Research Institute. 2015. "Mineral Oil—Livestock." Technical Review. Washington, DC: USDA/AMS/NOP. https://www.ams.usda.gov/sites/default/files/media/Min%20oil%20Technical%20Evaluation%20Report%20%282015%29.pdf.

Peters, C.J., Bills, N.L., Wilkins, J.L., and Fick, G.W. 2009. "Foodshed Analysis and Its Relevance to Sustainability." *Renewable Agriculture and Food Systems* 24 (1): 1–7.

Petroleum Committee. 1964. "The Petroleum Refining Industry—Air Pollution Problems and Control Methods." *Journal of the Air Pollution Control Association* 14 (1): 30–33. https://doi.org/10.1080/00022470.1964.10468237.

Petry, T., Bury, D., Fautz, R., Hauser, M., Huber, B., Markowetz, A., Mishra, S., Rettinger, K., Schuh, W., and Teichert, T. 2017. "Review of Data on the Dermal Penetration of Mineral Oils and Waxes Used in Cosmetic Applications." *Toxicology Letters* 280 (October): 70–78. https://doi.org/10.1016/j.toxlet.2017.07.899.

Pinholt, Y., Struwe, S., and Kjøller, A. 1979. "Microbial Changes during Oil Decomposition in Soil." *Ecography* 2 (3): 195–200.

Pless, C.D., Deyton, D.E., and Sams, C.E. 1995. "Control of San Jose Scale, Terrapin Scale, and European Red Mite on Dormant Fruit Trees with Soybean Oil." *HortScience* 30 (1): 94–97.

Pyenson, L.L. 1951. *Elements of Plant Protection*. New York, NY: John Wiley & Sons.

Ragothaman, A., and Anderson, W.A. 2017. "Air Quality Impacts of Petroleum Refining and Petrochemical Industries." *Environments* 4 (3): 66.

Ray, H.A., and Hoy, M.A. 2014. "Effects of Reduced-Risk Insecticides on Three Orchid Pests and Two Predacious Natural Enemies." *Florida Entomologist* 97 (3): 972–978.

Regnault-Roger, C. 1997. "The Potential of Botanical Essential Oils for Insect Pest Control." *Integrated Pest Management Reviews* 2 (1): 25–34.

Reilly, S.K., and Stewart, J. 1994. "Mutagenicity Studies for Petroleum Distillates, Oils, Solvents, or Hydrocarbons." 063503–000862. Washington DC: U.S. EPA. https://www3.epa.gov/pesticides/chem_search/cleared_reviews/csr_PC-063503_23-Mar-94_007.pdf.

Rodale, J.I. 1961. *How to Grow Vegetables and Fruit by the Organic Method*. Emmaus, PA: Rodale.

Rosset, P.M., and Altieri, M.A. 1997. "Agroecology versus Input Substitution: A Fundamental Contradiction of Sustainable Agriculture." *Society & Natural Resources* 10 (3): 283–295.

Sams, C., and Deyton, D. 2002. "Botanical and Fish Oils: History, Chemistry, Refining, Formulation and Current Uses." In *Spray Oils Beyond 2000: Sustainable Pest and Disease Management*, edited by Beattie, G.A.C., Watson, D.M., Stevens, M.L., Rae, D.J., and Spooner-Hart, R.N. 19–28. Sydney, Australia: University of Western Sydney.

Sarkar, D., Ferguson, M., Datta, R., and Birnbaum, S. 2005. "Bioremediation of Petroleum Hydrocarbons in Contaminated Soils: Comparison of Biosolids Addition, Carbon Supplementation, and Monitored Natural Attenuation." *Environmental Pollution* 136 (1): 187–195.

Scherr, K., Aichberger, H., Braun, R., and Loibner, A.P. 2007. "Influence of Soil Fractions on Microbial Degradation Behavior of Mineral Hydrocarbons." *European Journal of Soil Biology* 43 (5): 341–50. https://doi.org/10.1016/j.ejsobi.2007.03.009.

Simon, S., Bouvier J., Debras, J., and Sauphanor, B. 2011. "Biodiversity and Pest Management in Orchard Systems." In *Sustainable Agriculture Volume 2*, 693–709. Springer.

Simons, J.N. 1982. "Use of Oil Sprays and Reflective Surfaces for Control of Insect-Transmitted Plant Viruses." In *Pathogens, Vectors, and Plant Dieases: Approaches to Control*, edited by Harris, K.F. and Maramorosch, K., 71–93. New York, NY: Academic.

Smith, E.H., and Pearce, G.W. 1948. "The Mode of Action of Petroleum Oils as Ovicides." *Journal of Economic Entomology* 41 (2): 173–180.

Smith, E.H., and Salkeld, E.H. 1966. "The Use and Action of Ovicides." *Annual Review of Entomology* 11 (1): 331–368.

Söhngen, N.L. 1906. "Über Bakterien, Welche Methan Als Kohlenstoffnahrung Und Energiequelle Gebrauchen." *Zentrabl Bakteriol Parasitenk Infektionskr* 15: 513–517.

Song, B., Zhang, J., Wiggins, N.L., Yao, Y., Tang, G., and Sang, X. 2012. "Intercropping with Aromatic Plants Decreases Herbivore Abundance, Species Richness, and Shifts Arthropod Community Trophic Structure." *Environmental Entomology* 41 (4): 872–879.

Speight, J.G. 2015. *Handbook of Petroleum Product Analysis*. 2nd ed. Vol. 182. Hoboken, NJ: Wiley.

Swezey, S.L., Vossen, P., Caprile, J., and Bentley, W. 2000. *Organic Apple Production Manual*. Vol. 3403. UCANR Publications.

Szentkirályi, F. 2001. "Lacewings in Fruit and Nut Crops." In *Lacewings in the Crop Environment*. Cambridge, UK: Cambridge University Press.

Szewczyk, B., Hoyos-Carvajal, L., Paluszek, M., Skrzecz, I., and De Souza, M.L. 2006. "Baculoviruses—Re-Emerging Biopesticides." *Biotechnology Advances* 24 (2): 143–160.

Tauber, M.J., Tauber, C.A., Daane, K.M., and Hagen, K.S. 2000. "Commercialization of Predators: Recent Lessons from Green Lacewings (Neuroptera: Chrysopidae: Chrosoperla)." *American Entomologist* 46 (1): 26–38. https://doi.org/10.1093/ae/46.1.26.

Taverner, P.D., Sutton, C., Cunningham, N.M., Dyson, C., Lucas, N., and Myers, S.W. 2011. "Efficacy of Several Insecticides Alone and with Horticultural Mineral Oils on Light Brown Apple Moth (Lepidoptera: Tortricidae) Eggs." *Journal of Economic Entomology* 104 (1): 220–224.

Thomas, A.L., Muller, M.E., Dodson, B.R., Ellersieck, M.R., and Kaps, M. 2004. "A Kaolin-Based Particle Film Suppresses Certain Insect and Fungal Pests While Reducing Heat Stress in Apples." *Journal of the American Pomological Society* 58 (1): 42.

UC IPM. 2017. "Precautions for Using Petroleum Oil Sprays." 2017. http://ipm.ucanr.edu/PMG/r107301011.html.

Urbaneja, A., Pascual-Ruiz, S., Pina, T., Abad-Moyano, R., Vanaclocha, P., Montón, H., Dembilio, O., Castañera, P., and Jacas, J.A. 2008. "Efficacy of Five Selected Acaricides against *Tetranychus Urticae* (Acari: Tetranychidae) and Their Side Effects on Relevant Natural Enemies Occurring in Citrus Orchards." *Pest Management Science* 64 (8): 834–842.

U.S. Energy Information Administration (EIA). 2018. *Oil and Petroleum Products*. https://www.eia.gov/energyexplained/index.php?page=oil_home.

U.S. Environmental Protection Agency (EPA). 2004. "Complete List of Inert Ingredients by CAS Number (Obsolete)." https://www.epa.gov/sites/production/files/2016-05/documents/cascomplete.pdf.

———. 2007. "Aliphatic Solvents Revised Reregistration Eligibility Decision." Re-registration Eligibility Decision 3004. Arlington, VA: U.S. EPA Office of Pesticide Programs.

https://www3.epa.gov/pesticides/chem_search/reg_actions/reregistration/red_PC-063503_29-Nov-07.pdf.

———. 2016. "Basic Information about Oil and Natural Gas Air Pollution Standards." Washington DC: US EPA. https://www.epa.gov/controlling-air-pollution-oil-and-natural-gas-industry/basic-information-about-oil-and-natural-gas.

———. 2018. "Inert Finder." 2018. https://iaspub.epa.gov/apex/pesticides/f?p=121:1:::::

U.S. EPA PPLS. 2018. "Pesticide Product Labeling System." 2018. http://iaspub.epa.gov/apex/pesticides/f?p=PPLS:1.

U.S. Food and Drug Administration (FDA). 2018. "Substances Added to Food (Formerly EAFUS)." 2018. https://www.fda.gov/Food/IngredientsPackagingLabeling/FoodAdditivesIngredients/ucm115326.htm.

Van Hamme, J.D., Singh, A., and Ward, O.P. 2003. "Recent Advances in Petroleum Microbiology." *Microbiology and Molecular Biology Reviews* 67 (4): 503–549.

Van Overbeek, J., and Blondeau, R. 1954. "Mode of Action of Phytotoxic Oils." *Weeds* 3 (1): 55–65.

Vandermeer, J., Perfecto, I., and Philpott, S. 2010. "Ecological Complexity and Pest Control in Organic Coffee Production: Uncovering an Autonomous Ecosystem Service." *BioScience* 60 (7): 527–37.

Varjani, S.J. 2017. "Microbial Degradation of Petroleum Hydrocarbons." *Bioresource Technology* 223: 277–286.

Villanueva-Jiménez, J.A., and Hoy, M.A. 1998. "Toxicity of Pesticides to the Citrus Leafminer and Its Parasitoid *Ageniaspis Citricola* Evaluated to Assess Their Suitability for an IPM Program in Citrus Nurseries." *BioControl* 43 (3): 357–388.

Vogue, P.A., Kerle, E.A., and Jenkins, J.J. 1994. "Pesticide Properties Database." July 24, 1994. http://npic.orst.edu/ingred/ppdmove.htm.

Volck, W.H. 1929. Insecticide and process of making and using the same to protect plants. U.S. Patent Office 1,707,465, issued April 2, 1929.

Voorhees, V. 1937. Insecticidal oil spray. U.S. Patent Office, issued October 26, 1937.

Wake, H. 2005. "Oil Refineries: A Review of Their Ecological Impacts on the Aquatic Environment." *Estuarine, Coastal and Shelf Science* 62 (1–2): 131–140.

Weinzierl, R.A. 2000. "Botanical Insecticides, Soaps, and Oils." In *Biological and Biotechnological Control of Insect Pests*, by Rechcigl J.E., and Rechcigl, N.A., 101–21. Boca Raton, FL: Lewis.

Williams, T., Valle, J., and Viñuela, E. 2003. "Is the Naturally Derived Insecticide Spinosad® Compatible with Insect Natural Enemies?" *Biocontrol Science and Technology* 13 (5): 459–475.

Wins-Purdy, A.H., Whitehouse, C., Judd, G.J.R., and Evenden, M.L. 2009. "Effect of Horticultural Oil on Oviposition Behaviour and Egg Survival in the Obliquebanded Leafroller (Lepidoptera: Tortricidae)." *The Canadian Entomologist* 141 (1): 86–94.

Wyss, E., Luka, H., Pfiffner, L., Schlatter, C., Gabriela, U., and Daniel, C. 2005. "Approaches to Pest Management in Organic Agriculture: A Case Study in European Apple Orchards." CABI.

Yang, Y., Beattie, G.A.C., Spooner-Hart, R.N., Huang, M., Barchia, I., and Holford, P. 2013. "Influences of Leaf Age and Type, Non-Host Volatiles, and Mineral Oil Deposits on the Incidence, Distribution, and Form of Stylet Tracks of *Diaphorina Citri*." *Entomologia Experimentalis et Applicata* 147 (1): 33–49.

Yepsen, R.B., ed. 1984. *Encyclopedia of Natural Insect & Disease Control*. Emmaus, PA: Rodale press.

Yoder, K., Yuan, R., Combs, L., Byers, R., McFerson, J., and Schmidt, T. 2009. "Effects of Temperature and the Combination of Liquid Lime Sulfur and Fish Oil on Pollen Germination, Pollen Tube Growth, and Fruit Set in Apples." *HortScience* 44 (5): 1277–1283.

Youngquist, W. 1999. "The Post-Petroleum Paradigm—and Population." *Population and Environment* 20 (4): 297–315.

Zehnder, G., Gurr, G.M., Kühne, S., Wade, M.R., Wratten, S.D., and Wyss, E. 2007. "Arthropod Pest Management in Organic Crops." *Annu. Rev. Entomol.* 52: 57–80.

Zobell, C.E. 1946. "Action of Microörganisms on Hydrocarbons." *Bacteriological Reviews* 10 (1–2): 1.

Appendix 1

Table 1

Physical and Chemical Properties of Mineral Oil

Property	Characteristic / Value
Physical state at 25°C / 1 Atm. (CAS #8012-95-1)[1]	Liquid
Color[2]	Colorless
Odor[2]	Essentially odorless
Density / Specific Gravity[2]	0.875-0.905
API Gravity (various spray oils)[4]	32.8–34.3 API Gravity
Melting point[3]	-91.21°F (-68.45°C)
Boiling point (various spray oils)[4]	50% b.p: 415° to 440°F ±8°F (212° to 227°C ±4°C)
Pour point (various spray oils)[4]	-5° to -20° F (-21° to -29°C)
Flash point[4]	380°F (193°C)
Solubility[2]	Insoluble in water
Vapor pressure[2]	<0.5 mm Hg @ 20°C
Log K_{ow} coefficient[3]	5.18
Viscosity (various spray oils)[4]	57–83 seconds (10-38 cP)
Miscibility (CAS #8012-95-1)[1]	Miscible with most fixed oils; not miscible with castor oil; soluble in volatile oils
Storage stability (CAS #8012-95-1)[1]	Oxidizes at a logarithmic rate
Persistence[2,3]	Half-life of 74 hours; 2–3 days as a surface film

Sources: 1. HSDB 2015; 2. US EPA 2007; 3. EPI 2012 4. UC IPM 2017

Table 2
Description of the Various Active Ingredients found in Mineral Oil Pesticides

Chemical Name	CAS #	Description
Mineral oil, Oil mist (mineral)	8012-95-1	Liquid hydrocarbons from petroleum
Mineral oil; Hydrocarbon oils; paraffin liquid	8020-83-5	A mixture of liquid hydrocarbons obtained from petroleum
White mineral oil, petroleum	8042-47-5	A highly refined petroleum mineral oil consisting of a complex combination of hydrocarbons obtained from the intensive treatment of a petroleum fraction with sulfuric acid and oleum, or by hydrogenation, or by a combination of hydrogenation and acid treatment. Additional washing and treating steps may be included in the processing operation. It consists of saturated hydrocarbons having carbon numbers predominantly in the range of C15 through C50.
Distillates, petroleum., solvent-refined heavy paraffinic	64741-88-4	A complex combination of hydrocarbons obtained as the raffinate from a solvent extraction process. It consists predominantly of saturated hydrocarbons having carbon numbers predominantly in the range of C20 through C50 and produces a finished oil with a viscosity of at least 100 Sabolt Universal Seconds (SUS) at 100°F (19 centistokes [cSt] at 40°C).
Distillates, petroleum., solvent-refined light paraffinic	64741-89-5	A complex combination of hydrocarbons obtained as the raffinate from a solvent extraction process. It consists predominantly of saturated hydrocarbons having carbon numbers predominantly in the range of C15 through C30 and produces a finished oil with a viscosity of less than 100 SUS at 100°F (19cSt at 40°C).
Distillates, petroleum, hydrotreated heavy paraffinic	64742-54-7	A complex combination of hydrocarbons obtained by treating a petroleum fraction with hydrogen in the presence of a catalyst. It consists of hydrocarbons having carbon numbers predominantly in the range of C20 through C50 and produces a finished oil of at least 100 SUS at 100°F (19cSt at 40°C). It contains a relatively large proportion of saturated hydrocarbons.
Distillates, petroleum, hydrotreated light paraffinic	64742-55-8	A complex combination of hydrocarbons obtained by treating a petroleum fraction with hydrogen in the presence of a catalyst. It consists of hydrocarbons having carbon numbers predominantly in the range of C15 through C30 and produces a finished oil with a viscosity of less than 100 SUS at 100°F (19cSt at 40°C). It contains a relatively large proportion of saturated hydrocarbons.
Distillates, petroleum, solvent-dewaxed light paraffinic	64742-56-9	A complex combination of hydrocarbons obtained by removal of normal paraffins from a petroleum fraction by solvent crystallization. It consists predominantly of hydrocarbons having carbon numbers predominantly in the range of C15 through C30 and produces a finished oil with a viscosity of less than 100 SUS at 100°F (19cSt at 40°C).
Distillates, petroleum, solvent-dewaxed heavy paraffinic	64742-65-0	A complex combination of hydrocarbons obtained by removal of normal paraffins from a petroleum fraction by solvent crystallization. It consists predominantly of hydrocarbons having carbon numbers predominantly in the range of C20 through C50 and produces a finished oil with a viscosity not less than 100 SUS at 100° F (19cSt at 40°C).

Chemical Name	**CAS #**	**Description**
Lubricating oils, petroleum C15-30, hydrotreated neutral oil based, containing. solvent deasphalted residual oil	72623-84-8	A complex combination of hydrocarbons obtained by treating light vacuum gas oil, heavy vacuum gas oil, and solvent deasphalted residual oil with hydrogen in the presence of a catalyst in a two-stage process with dewaxing being carried out between the two stages. It consists predominantly of hydrocarbons having carbon numbers predominantly in the range of C15 through C30 and produces a finished oil having a viscosity of approximately 10cSt at 40°C (104°F). It contains a relatively large proportion of saturated hydrocarbons.
Lubricating oils, petroleum, C15-30, hydrotreated neutral oil-based	72623-86-0	A complex combination of hydrocarbons obtained by treating light vacuum gas oil and heavy vacuum gas oil with hydrogen in the presence of a catalyst in a two-stage process and dewaxing being carried out between the two stages. It consists predominantly of hydrocarbons having carbon numbers predominantly in the range of C15 through C30 and produces a finished oil having a viscosity of approximately 15cSt at 40°C. It contains a relatively large proportion of saturated hydrocarbons.
Lubricating oils, petroleum, C20-50, hydrotreated neutral oil-based	72623-87-1	A complex combination of hydrocarbons obtained by treating light vacuum gas oil, heavy vacuum gas oil and solvent deasphalted residual oil with hydrogen in the presence of a catalyst in a two-stage process with dewaxing being carried out between the two stages. It consists primarily of hydrocarbons having carbon numbers predominantly in the range of C20 through C50 and produces a finished oil with a viscosity of approximately 32cSt at 40°C. It contains a relatively large proportion of saturated hydrocarbons.

Source: (US EPA 2007)

Table 3
EPA Labeled Food Crops, Target Organisms, and Applications for Mineral Oil

Crop	Pests and Diseases	Time(s) of Application	Max. App. Rate (lb ai/A unless noted otherwise)
Acerola	Aphids, Mites, Beetle larvae, Leafminers, Thrips, Leafhopper, Whitefly, Powdery Mildew	When needed	0.07 lb ai/gal
Alfalfa	Aphids, Mites, Leafminers, Rootworm, Whitefly	When needed	14.0
Almonds	Aphids, Scales, Spider mites	Dormant & Summer	123.3
Apples	Aphids, Codling moth, Scales, Mites, Fruit Tree Leaf Rollers, Apple red bug, Powdery mildew	Dormant & Summer	164.4 dormant 84.2 summer
Apricot	Scales, Mites	Dormant & Summer	123.3 dormant 84.2 summer
Artichoke (Chinese)	Aphids, Mites, Beetle larvae, Leafminers, Thrips, Leafhopper, Whitefly, Powdery Mildew	When needed	0.07 lb ai/gal
Asparagus	Aphids, Mites, Beetle larvae, Leafminers, Thrips, Leafhopper, Whitefly	When needed	0.07 lb ai/gal
Atemoya	Aphids, Mites, Beetle larvae, Leafminers, Thrips, Leafhopper, Whitefly, Powdery Mildew	When needed	0.07 lb ai/gal
Avocados	Aphids, Mealybugs, Mites, Scales, Whitefly	When needed	209.6
Bananas/Plantains	Black leaf streak, Yellow sigatoka	Year-round	10.6
Balm	Aphids, Mites, Beetle larvae, Leafminers, Thrips, Leafhopper, Whitefly	When needed	0.07 lb ai/gal
Basil	Aphids, Mites, Beetle larvae, Leafminers, Thrips, Leafhopper, Whitefly	When needed	0.07 lb ai/gal
Beans	Aphids, Mites, Beetle larvae, Leafminers, Thrips, Leafhopper, Whitefly	When needed	0.07 lb ai/gal
Beets (unspecified)	Aphids, Mites, Beetle larvae, Leafminers, Thrips, Leafhopper, Whitefly	When needed	0.07 lb ai/gal
Blueberries	Scales, Mites, Rust, Powdery mildew	Dormant & Summer	10.6
Caneberries (blackberries, boysenberries, raspberries)	Mites, Scales, Rust, Powdery mildew	Dormant & Summer	10.6
Celery	Aphids, Mites, Beetle larvae, Leafminers, Thrips, Leafhopper, Whitefly	When needed	0.07 lb ai/gal
Cherries	Scales	Dormant	123.3 dormant 84.2 summer
Citrus (unspecified)	Mites, Scale, Whiteflies, Greasy spot disease, Sooty mold	Year-round	139.2
Coffee	Scales	Year-round	42.4
Cole Crops (Broccoli, Cabbage, Chinese Broccoli, Cauliflower	Aphids, Mites, Beetle larvae, Leafminers, Thrips, Leafhopper, Whitefly	When needed	0.07 lb ai/gal

Crop	**Pests and Diseases**	**Time(s) of Application**	**Max. App. Rate (lb ai/A unless noted otherwise)**
Corn	Aphids, Mites, Leafminers, Ear Worms, Fall Army Worm, Corn Root Worm, Whitefly	When needed	7.0
Cucurbits (Gourds, Melons, Pumpkins, Squash)	Aphids, Mites, Beetle larvae, Leafminers, Thrips, Leafhopper, Whitefly, Powdery Mildew	When needed	0.07 lb ai/gal
Eggplant	Aphids, Mites, Beetle larvae, Leafminers, Thrips, Leafhopper, Whitefly	When needed	0.07 lb ai/gal
Fig	Scales	Dormant	21.17
Ginger	Aphids, Mites, Beetle larvae, Leafminers, Thrips, Leafhopper, Whitefly, Powdery Mildew	When needed	0.07 lb ai/gal
Ginseng	Aphids, Mites, Beetle larvae, Leafminers, Thrips, Leafhopper, Whitefly, Powdery Mildew	When needed	0.07 lb ai/gal
Grapefruit	Mites, Scales	When needed	469.2
Grapes	Mealybugs, Scales, Leafhopper, Powdery mildew	Dormant, Postharvest	41.6
Hops	Mites, powdery mildew	Foliar & Postharvest	38.5
Kiwi Fruit	Scales	When needed	42.3
Lemon & Lime	Mites, Scales	When needed	469.2
Lettuce	Aphids, Mites, Beetle larvae, Leafminers, Thrips, Leafhopper, Whitefly	When needed	0.07 lb ai/gal
Mango	Aphids, Mealybugs, Mites, Scales, Whitefly, Powdery mildew	When needed	10.6
Marjoram/Oregano[1]	Aphids, Mites, Beetle larvae, Leafminers, Thrips, Leafhopper, Whitefly	When needed	0.07 lb ai/gal
Mint/Peppermint/ Spearmint	Aphids, Mites, Beetle larvae, Leafminers, Thrips, Leafhopper, Whitefly	When needed	0.07 lb ai/gal
Nectarines	Fruit Tree Leaf Rollers, Scales, Psylla, mites	Dormant	123.3 dormant 84.23 summer
Olives	Scales	Post-harvest, Pre-bloom	156.4
Oranges	Mites, Scales, Whitefly, Blackfly, Sooty mold	When needed	469.2
Papaya	Mites, Powdery mildew, Papaya ringspot	When needed	10.584
Peaches	Scales	Dormant	123.3
Pears	Aphids, Mites, Psylla, Scale, Codling moth (eggs)	Dormant & Summer	164.4
Pecan[2]	Aphids, Scale, Mites, Phylloxera	When needed	56.5
Pepper	Aphids, Mites, Beetle larvae, Leafminers, Thrips, Leafhopper, Whitefly	When needed	0.07 lb ai/gal
Persimmons	Leafrollers, Scales, Book Lice	When needed	0.07 lb ai/gal
Pineapple	Mealybugs, Bud Moth, Chinese Rose Beetle	When needed	14.1
Pistachio	Mites, Scales	Dormant	123.3
Plums/Prunes	Mites, Scales	Dormant & Summer	123.3 summer 84.2 dormant
Potatoes (white/ Irish)	Aphids, Mites, Beetle larvae, Leafminers, Thrips, Leafhopper, Whitefly	When needed	0.07 lb ai/gal

Crop	**Pests and Diseases**	**Time(s) of Application**	**Max. App. Rate (lb ai/A unless noted otherwise)**
Radish	Aphids, Mites, Beetle larvae, Leafminers, Thrips, Leafhopper, Whitefly	When needed	0.07 lb ai/gal
Spinach	Aphids, Mites, Beetle larvae, Leafminers, Thrips, Leafhopper, Whitefly, Powdery Mildew	When needed	0.07 lb ai/gal
Strawberries	Aphids, Mites	When needed	0.05 lb ai/gal
Sugar beets	Mites, Leaf miner	When needed	0.14 lb ai/gal
Sweet potatoes	Aphids, Mites, Beetle larvae, Leafminers, Thrips, Leafhopper, Whitefly	When needed	0.07 lb ai/gal
Tangelo/Tangerines[3]	Mites, Scale, Whiteflies, Greasy spot disease, Sooty mold	When needed	469.2
Tobacco	Aphids, Mites, Beetle larvae, Leafminers, Thrips, Leafhopper, Whitefly	When needed	0.07 lb ai/gal
Tomatoes	Aphids, Mites, Beetle larvae, Leafminers, Thrips, Leafhopper, Whitefly	When needed	0.07 lb ai/gal
Walnuts	Scales, Aphids, Mites, Whiteflies	Dormant & Summer	55.7

Source: (US EPA 2007; US EPA PPLS 2018)

[1] Pests and diseases extrapolated from "Herbs and spices."

[2] Pests and diseases extrapolated from TGAI labels and extension recommendations.

[3] Pests and diseases extrapolated from "Citrus (unspecified)."

Table 4
EPA Inert Ingredient Statuses for Aliphatic Solvents

Chemical Name	CAS #	Cleared Uses	List
Mineral oil, Oil mist (mineral)	8012-95-1	Food and Nonfood	3
Mineral oil; Hydrocarbon oils; paraffin liquid	8020-83-5	Not found	3
White mineral oil, petroleum	8042-47-5	Food and Nonfood	4A
Distillates, petroleum., solvent-refined heavy paraffinic	64741-88-4	Not found	3
Distillates, petroleum., solvent-refined light paraffinic	64741-89-5	Food, Nonfood, and Fragrances	3
Distillates, petroleum, hydrotreated heavy paraffinic	64742-54-7	Food and Nonfood	2
Distillates, petroleum, hydrotreated light paraffinic	64742-55-8	Not found	2
Distillates, petroleum, solvent-dewaxed light paraffinic Conforming to 21 CFR 172.844 or 21 CFR 178.3650	64742-56-9	Food and Nonfood	2
Distillates, petroleum, solvent-dewaxed heavy paraffinic	64742-65-0	Food and Nonfood	2
Lubricating oils, petroleum C15-30, hydrotreated neutral oil based, containing. solvent deasphalted residual oil	72623-84-8	Not found	3
Lubricating oils, petroleum, C15-30, hydrotreated neutral oil-based	72623-86-0	Not found	3
Lubricating oils, petroleum, C20-50, hydrotreated neutral oil-based	72623-87-1	Not found	3

(US EPA 2004, 2018)

Table 5
Toxicity of Mineral Oil

Study	Results	Source(s)
Acute oral toxicity	Rat: >5 g / kg	(Chin and Stewart 1994)
Acute dermal toxicity	Rabbit: >2 g / kg (CAS 64742-54-7) Rat: > 5 g / kg (CAS 64742-56-9)	(Chin and Stewart 1994; US EPA 2007)
Acute inhalation	Rat: > 4.7 mg / L Rat: 3,900 mg / m^3 (CAS 64742-55-8)	(Chin and Stewart 1994)
Acute eye irritation	Rat: Slight eye irritant. Eye irritation (slight conjunctival redness) did not clear at day 14 (last day of observation); Moderate effect at 500 mg	(Chin and Stewart 1994; NIOSH 2003)
Acute dermal irritation	Guinea pig: Mild effect at 100 mg for 24 hr Rabbit: Mild effect at 100 mg for 24 hr	(NIOSH 2003)
Skin sensitization	Guinea pig: Not a dermal sensitizer	(US EPA 2007)
28-day dermal	Mice: NOEL > 2,000 mg/kg/day	(US EPA 2007)
28-day inhalation	Rats: LOEL = 520 mg/m^3 (146.6 mg/kg/day)	(US EPA 2007)
90-day inhalation	Rats: NOEL=0.1 mg/L (26.1 mg/kg/day)	(US EPA 2007)
Reproduction / development toxicity screening test	Minor malformations within the normal ranges observed at doses between 900-4,500 mg/kg-bw/day	(US EPA 2007)
Mutagenicity	Ames test: Inconclusive or Weakly mutagenic	(Reilly and Stewart 1994; EFSA 2012)
Carcinogenicity	Untreated and mildly-treated mineral oils are carcinogenic to humans; highly refined oils are not classifiable as to their carcinogenicity to humans.	(IARC 2012)
Fish	No lethality observed in any fish species tested.	(US EPA 2007)
Daphnia	EC50=0.1->0.9 mg/L NOEC: 0.023 ppm LC50=0.2->14.0 mg/L	(Drotter and Krueger 1999; US EPA 2007)
Oysters	EC=6 mg/L	(US EPA 2007)
Birds	Northern Bobwhite: LD50>2,250 mg/kg-bw Mallard & Northern Bobwhite: LC50>5,260 ppm	(Long et al. 1990; Gallagher, Grimes, and Beavers 1998, 1999a, 1999b; US EPA 2007)