# Ethylene

## Crops

## Identification

**Chemical Names** ethylene
**Other Names:** ethene, elayl, olefiant gas

**CAS Numbers:** 74-85-1
**Other Codes:** DOT #: UN 1962/UN 1938

## Characterization

**Composition** $C_2H_4$ ($CH_2=CH_2$)

**Properties:**
A colorless, flammable gas with a slightly sweet odor, soluble in water.

**How Made:**
Made from hydrocarbon feedstocks, such as natural gas liquids or crude oil. Produced almost exclusively from the pyrolysis of hydrocarbons in tubular reactor coils installed in externally fired heaters. These heaters are operated at high temperatures (750-900°C), short residence times (0.1-0.6s), and low hydrocarbon partial pressure. Steam is added.

Ethylene may also be produced from ethanol in fixed or fluid-bed reaction systems. This means it could be made from biomass fermentation, but that is not currently done in the U.S. The amount of heat necessary for this process would still result in what may be considered a "synthetic" material. Ethylene is given off naturally by ripening fruit and by some micro-organisms. These sources of ethylene have never been harnessed commercially.

**Specific Uses:**
Ripening and coloring fruit, including bananas, pears, mangoes, tomatoes and citrus. Induces flowering in pineapples when applied in the field. Can be used to improve growth and appearance of bean sprouts.

**Action:**
Acts like the natural form of the plant growth regulator by accelerating the ripening process through an exact mechanism that is not fully understood. Many volumes of technical information have been generated in books and journals about ethylene's effects on plants and theories about the mode of action. In general the gas is produced in fruit when physiological maturity is reached and the gas triggers the chemical changes which take place at ripening. In pineapple, the gas is generated at vegetative maturity of the plant which triggers the flowering and fruiting cycle.

**Combinations:**
One of the more commonly used forms is the ethylene generating chemical, (2-chloroethyl) phosphonic acid, known as ethephon. This is mostly used for pre-harvest applications with the only post-harvest one being the degreening of lemons in Florida (Sherman, 1985). "Banana gas" is pure ethylene gas in a compressed cylinder which is diluted with an inert gas, usually nitrogen.

## Status

### OFPA
For crop use it could be considered a production aid but is not specifically mentioned in any of the exempt categories in 6517(1)(B)(i).

### Regulatory
Ethylene is regarded legally as a pesticide for regulatory purposes. It must be registered with the EPA and appropriate state agencies.

**Status among Certifiers**
Allowed for post-harvest use on bananas only. (NOSB recommendation, OMRI list)

**Historic Use**
Allowed for use on bananas by many organic certifiers and state programs. Some certifiers have certified tropical fruit drying facilities that use ethylene for mango ripening. Generally not allowed for sprouts.

**International**
IFOAM - not mentioned. CODEX - not mentioned specifically.

## OFPA 2119(m) Criteria

(1) The potential of such substances for detrimental chemical interactions with other materials used in organic farming systems.

"Detrimental chemical interactions with other materials used in organic farming" have not been identified in the literature.

(2) The toxicity and mode of action of the substance and of its breakdown products or any contaminants, and their persistence and areas of concentration in the environment.

Acute toxicity from direct exposure may include death of animals, birds, or fish and death or low growth rate in plants. Slight acute toxicity to aquatic life. Insufficient data are available to evaluate or predict the short-term or long-term effects of ethylene to birds or land animals. Chronic toxic effects may include shortened lifespan, reproductive problems, lower fertility, and others. Non-persistent in water, with a half-life of less than 2 days. About 99.9% will eventually end up in air; the rest in water. See discussion under environmental concerns.

(3) The probability of environmental contamination during manufacture, use, misuse or disposal of such substance.

Ethylene or olefin plants require extensive support facilities to comply with environmental regulations. These include boiler feed water preparation, treatment of noxious effluents, and steam and electric generation.

(4) The effect of the substance on human health.

Highly flammable and explosive. See discussion for more on explosiveness. Exposure to gas causes dizziness and could cause suffocation from decreasing the amount of oxygen.

(5) The effects of the substance on biological and chemical interactions in the agroecosystem, including the physiological effects of the substance on soil organisms (including the salt index and solubility of the soil), crops and livestock.
Natural soil ethylene levels are often higher than those in the air (Abeles, 1992). Applied ethylene will mostly go into the air as gas if it doesn't get absorbed by the plant, and so the contribution to soil ethylene of applied ethylene will be minimal. Ethylene is readily metabolized by many soil organisms. Ironically, ethylene can stimulate the germination of fungal spores both in the soil and on the surface of fruit (Clendennen, 1997).

(6) The alternatives to using the substance in terms of practices or other available materials.

Natural ripening alternatives: temperature control, mix with apples for natural ethylene generation. The alternative for induction of flowering in pineapples is calcium carbide used to form acetylene. See discussion for details. The alternative for sprout production is to do without ethylene and get inferior production, or to use ethylene generated by a different means if possible to develop a natural source.

A small farmer may ripen a stalk of bananas by putting it in the trunk of his car on a hot day. By the time he finishes going surfing for the morning, the stalk could be ripe and ready to market. This could be considered a natural ripening process. However, a larger scale farmer is likely to have a ripening room in which the temperature and atmosphere can be controlled. The appropriate amount of ethylene would be maintained with help from synthetically produced ethylene gas.

(7) Its compatibility with a system of sustainable agriculture.
See the discussion section below for comments on the compatibility of ethylene with a system of sustainable agriculture.

## Discussion

History
The first use of natural ethylene in fruit ripening was described in the Bible. The prophet Amos was described as a "gasher and gatherer" of figs. Gashing figs was known to promote stress ethylene production mimicking the action of the wasps when they exit pollinated fruits, and this triggered ripening. Also in ancient times the Chinese placed weighted lids on growing bean sprouts to promote hypocotyl thickening and crispness (Abeles, 1992). Ethylene was used unknowingly to ripen bananas in both East Africa and Samoa by burying them in fire-warmed pits, thus using residual ethylene from the smoke of the fire as the ripening agent.

In more recent times it was discovered that warming citrus fruit with kerosene heaters in closed spaces caused a degreening effect that wasn't just due to the heat (Denny, 1924). In the 1920's it was shown that the cause of this ripening effect was ethylene gas, which fortunately was already being produced commercially for other purposes (Chace, 1934). In the 1930's it was verified that ethylene was indeed produced by plants and that this gas was the same composition as that given off by the kerosene heaters (Abeles, 1992). In the years following this, researchers determined that ethylene produced a variety of effects in plants and it could be classified as a plant hormone, or more correctly, a plant growth regulator.

Concern was voiced early on in the commercial exploitation of ethylene about the residual effects of ethylene treatment; that it would be used to allow inferior fruit to be sold at a higher price. Researchers then showed that the ethylene treated fruit were equivalent in quality and "healthfulness" to naturally ripened fruit (Chace, 1934). This is largely because the fruit must have reached its physiological green maturity stage in order to respond to external ethylene, and then the ripening changes triggered by ethylene are essentially the same between the treated and naturally ripened fruit. These changes include starch and sugar content, acidity and concentration of pectic substances (Clendennen, 1997). There have been no consistent studies indicating any difference in flavor between bananas ripened with or without ethylene (Scriven et al., 1989; Watada, 1986).

Environmental Concerns
The main safety concern in relation to ethylene use has been due to the explosive nature of the gas in the air. This is of primary concern in design and operation of ethylene application facilities. Both the EPA, local fire marshal rules, and insurance companies have very specific labelling and registration requirements for the ethylene itself and the process used to apply it, down to the electirical wiring and piping used in ripening rooms. Note that the gas is explosive in air at concentrations from 3.1% to 32% (31,000 to 320,000 ppm). The minimum explosive concentration (3.1%) exceeds the suggested ethylene concentrations for tomato ripening and citrus degreening respectively by 200 and 6200 times (Sherman, 1985). The "banana gas" and catalytic generator sources of ethylene are considered the safest because they are more easily monitored, but explosive accidents have happened in the past and operaors should be well trained and prepared (Sherman, 1985).

Another concern with ethylene is the issue of air pollution. The amount of ethylene given off from either manufacturing or ethylene treatment facilities is miniscule compared to the ethylene released into the air from hydrocarbon emissions from auto exhaust, petrochemical plants or even fires. There are no national air quality standards for ethylene levels, but there are some from the American Industrial Hygiene Association (Abeles, 1992). Ethylene is degraded in the atmosphere by UV light present in sunlight. Ethylene air pollution can reduce ozone pollution. It can however be present in strong enough concentration to produce phytotoxic effects.

<u>Nutrition Effects</u>
While the effects of ethylene on the ripening process have been studied well for both bananas and pineapple, there is no clear and consistent evidence that artificially ripened or induced fruit has any more or less nutritive value than naturally ripened fruit (Chace, 1934; Abeles, 1992; Clendennen, 1997). If anything, pineapple treated with ethylene had increased sugars, proteins, fruit acid and soluble solids, but lower fruit weight (Mwaule, 1985; Ahmed, 1987)

<u>Specific Uses: Pineapple Flowering</u>
While the cultural techniques for pineapple may not be well known here in the US, pineapple is a large economic crop on several continents and in many countries. The market for organic pineapple has been quite small so far but it could expand dramatically with the demand for processing pineapple on the upswing. The issue limiting pineapple production at this time is the use of a material, either ethylene or calcium carbide, to induce flowering (see petitions from Made in Nature, TropOrganics S.A., Pina Perfecta S.A., and Eco-LOGICA). The literature does support the petitioners in that a crop of sufficient size, uniformity, and ripening period cannot be produced without something to induce flowering (Abeles 1992; Bose, 1983; Williams, 1987; Lacoeuilhe, 1983)

Flowering in pineapple occurs when plants reach a certain size. While some research shows an enhancement in flowering from short days, low night temperatures and water stress, the flowering can happen in one field at quite different times because the plants have been growing for at least 20 months before they start to flower (Reinhardt, et al, 1986). Different pineapple regions also report quite different results about what triggers natural flowering. All recommendations for pineapple culture suggest using a material for flower induction to acheive even flowering and a uniform harvesting period. While the induction can result in producing a crop out of season, it is also necessary to produce a uniform crop in season. This is considered important for processing as well as for predictable marketing of the crop, as most pineapple is grown for export and a shipping container must be filled for each harvest.

Studies have not reported any overall influence upon yield or fruit quality as long as the pineapple plants are mature enough when treated (Mwaule, 1985; Dalldorf, 1985). The yields will be spread out over several years without the flower induction however.

Numerous chemicals have been studied for their usefulness in flower induction, including NAA (Naphthaleneacetic acid), Urea, Ethylene (mostly Ethephon) (with or without Activated Charcoal), CCC (chlormequat), GA3 (gibberellic acid) and Calcium Carbide/Acetylene. The petitions received by the NOSB are for Ethylene and Calcium Carbide/Acetylene. These two systems both need to be discussed, for either or none to be selected.

> 1. Ethylene - Normally applied to the plants at 12 to 24 months in the form of Ethephon at a rate of 25 to 100 ppm. Can be mixed with either urea or activated charcoal as carrier, or applied alone. Flower induction is triggered in 25 to 45 days, depending on time of year, size of plant, and temperature. The ethylene breaks down either in the plant cells or is volatilized into the air very quickly. Activated charcoal is made from steam treatment of natural coal or carbonized wood materials and would be considered to be natural. Ethylene is considerably more expensive than calcium carbide.
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> 2. Calcium carbide/Acetylene - Calcium carbide is a synthetic material made from limestone or quicklime mixed with crushed coke at high temperatures. Its chemical formula is $CaC_2$ and CAS number is 75-20-7. When sprayed on the plants in water it forms acetylene gas which is a precursor to ethylene. The acetylene enters the plant and is transformed into ethylene in the cells, thus triggering flowering. A study of the subject by Oregon Tilth (Coody, 1996) determined that the calcium carbide and acetylene are considered synthetic under OFPA, while the ethylene made by the plants, being made from a "naturally occuring biological process" (OFPA, 1990), would be considered natural.
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> Besides acetylene created from the reaction of calcium carbide and water, there is calcium hydroxide

produced. This is a prohibited synthetic material for organics as a fertilizer. Due to lack of information about the nature of calcium carbide, it was used by several of the petitioners and other growers under the mistaken impression that it was derived from limestone and therefore natural. It is also perceived (but there is no direct evidence behind this) to be more desireable from an organic point of view than ethylene use. A search of the literature has showed this perception to be mistaken, however, as there are impurities found in commercial calcium carbide which could be dangerous to human health (Sy & Wainwright, 1990). These include phosphorous hydride (PH3) and arsenic hydride (AsH3). These components might be found in the calcium hydroxide formed during the liberation of acetylene.

As far as which of the two materials works better, there seems to be considerable disagreement from region to region. Both work better than the control treatments, and in general better than the NAA or other chemicals tested (Bose, 1983; Prasad, 1987). Both materials as externally applied would be considered to be synthetic under OFPA and no testing was found in the literature of any material that would be considered natural. Because these materials are so simple chemically they could hypothetically be able to be formed naturally. Charcoal and limestone for instance, may be able to create the same effect as calcium carbide. Ethylene has possibilities of being generated naturally, either from micro-organisms, natural ethanol, or captured from ripening fruit. The production of organic pineapple is way too small at this time for these alternatives to be realistically explored.

In the several years which elapsed between the time of the petitions and now, the certifiers in pineapple producing countries have had to make a policy on their own. Communication in July of 1999 from the group Eco-LOGICA in Costa Rica, indicates that they gave a temporary approval to both calcium carbide and ethylene for a two year period from March of 1999 while they await an opinion from the USDA since the US is their most important market. Their reasons include not being able to satisfy market demand because of irregular flowering and thus harvest, research done by their own farmers in the field to try to find an allowed alternative but without success (these included exposing plants to ripe bananas, banana vinegar, manure, and copper sulfate), and determining that the ethylene gas as applied to pineapples does not pose a threat to worker's health or the environment.

Specific Uses: Bean Sprouts

About half of the bean sprouts commercially produced in California today are gassed with ethylene (Abeles, 1992). Both the growth and the quality of the sprouts are improved by this practice. In natural germination in soil a bean sprout is exposed to a higher concentration of ethylene that in the air and this improves the trasfer of nutrients from the cotyledon to the hypocotyl (future shoot to future root). When grown in large quantities out of the soil environment, any ambient ethylene is soon used up, and the addition of ethylene to sprout rooms at low concentrations mimics the atmosphere present in soil. Ethylene stimulates the physiological aspects of root growth (Abeles, 1992).

One organic sprout grower who has operations in Japan and California has developed a unique and proprietary technique for creating ethylene gas for sprout rooms from food grade ethyl alcohol. Although the ethanol is "natural", the process used involves heating it to 360°F and therefore needs a determination from the TAP reviewers as to whether this would be considered synthetically produced ethylene. Whether synthetic or natural, it also needs to be decided whether this use of ethylene is allowed for organic production. (see attached memo from CCOF to OMRI). The concentration used in the sprout rooms is about 0.1ppm, compared to the 10 ppm or more used for ripening bananas.

The NOSB has clearly stated in the past that combustion of biological materials is considered to be a "natural" process while combustion of minerals is not considered natural. There has not been a clear statement whether heating biological materials would be looked at in the same way as combustion. Both heating and combustion would result in some amount of chemical change (in the case of combustion a dramatic one!), but both of these processes happen in nature all the time. If a ruling were made on the heating issue, it would become clearer whether this process is considered to produce a "natural" end product.

Conclusions

This is one of the more difficult subjects facing the NOSB in the National List process. Ethylene as used today is a synthetic analog of a natural gas produced by plants. There is precedent in the previous NOSB recommendations for the approval of analogs of natural materials such as magnesium sulfate, copper sulfate, hydrogen peroxide and ethylene for bananas. There is also precedent for materials being used as plant growth regulators being approved by the NOSB, such as natural gibberelic acid and possibly amino acids.

The basic argument in force here is that agriculture is inherently not the same as a natural system, but organic agriculture can be thought of as an augmented natural system. The augmentation takes the form of materials and practices designed to acheive agricultural production of crops in sufficient quality and quantity for human consumption while maintaining the ecosystem without adding chemicals that have a lasting degradative impact. Ethylene fits this argument in most respects.

On the other hand, this material is being used out of its strictly natural context and is being used as a plant growth regulator to potentially "trick" plants into doing something they may not be ready to do naturally. It is formed from a synthetic process which could have negative environmental impacts from its manufacture. It may be able to be made from a natural starting point at some time in the future if the economic pressure is applied for that to happen.

## *Condensed Reviewer Comments*

None of the reviewers have a commercial or financial interest in ethylene.

Reviewer 1
As indicated, ethylene, if sourced from hydrocarbon feed stocks, must be considered synthetic. I agree with information presented and its technical accuracy (please refer to Ethylene- Processing Report for additional information). I also agree that ethylene use at the crops level is compatible with agro ecosystem biology since "natural soil ethylene levels are often higher than those in the air (Abeles, 1992) as indicated in OFPA criteria No. 2119(m)5. Again, I think the most important issue is purity and therefore would recommend that all ethylene used at the crop level, as a condition for use, be required to meet 100% purity standards as demonstrated by gas chromatography analysis at the manufacturers level. I would add this purity requirement as a proposed annotation. Additionally, I would broaden the use of ethylene to crops such as pineapples and bean sprouts and request growers who wish to use ethylene to submit a proposal for intended usage to NOSB for review.

Reviewer 2
Small scale organic pineapple growers may complain that it gives unfair advantage to the large growers. It is likely the price will drop for organic pineapples. The current prices for an organic pineapple are 2 to 5 time higher than conventional. This equates to a single large organic pineapple costing $7 to $10. For this reason availability to a larger market, i.e.. processing into juice or jams etc. is virtually nonexistent. Due to severe weeding problems on small scale farms (the pineapple plant pokes people trying to weed it) very few if any organic farms rely on pineapple as their sole crop. Large acreage for organic pineapple in Hawaii is considered anything above two acres. Small scale acreage for commercial pineapple could be 40 acres, large scale commercial pineapple farms use into the thousands of acres. Small scale farmers usually prefer to have a long ripening season to sell their high priced pineapples to the fresh market. They usually walk their fields daily to pick pineapples at their peak ripeness and shelf life. When climatic conditions create a sudden ripening of the fruit, the market price crashes and fruit is sold at below the cost of production. This possibility has limited organic pineapple as a crop.

Overall the impact of large scale organic pineapple production on the environment would be much better than the current conventional methods. Some entire islands have been covered with conventionally grown pineapples causing severe adverse impacts on the water, soil and the culture of the islands. Deteriorating plastic mulch blows everywhere in the fields. Their is major air spraying of toxic chemicals and heavy chemical use for fertilizing and weed control. If organic pineapple can work on the plantation scale, it would have a very beneficial impact on the islands and the ocean around them.

For bananas, the problem being dealt with is that a banana stalk does not ripen evenly. There can be up to a two week difference between the time the top of the stalk is ready to when the bottom is ready. For the home gardener this may work out quite conveniently. For the larger scale grower, this may lead to marketing problems. Retailers will only buy fruit with predicable ripening times and known shelf life.

D. Should it be added to National List of Allowed Synthetics?

a. Based on the rating of 8 (see appendix 1 “Criteria for Compatibility of Synthetic Materials in Organic Production”) It should be allowed with restrictions to mitigate the dangers to the person applying the material and also the manufacture of the material. The restrictions may be worded as follows; All safety requirements during application must be strictly followed and purchases of materials should come from producers who are in compliance with EPA environmental regulations.

b. It should be allowed in all cases and be considered as a synthetic-safe material

B. What if any changes should be made

1. Should also be allowed in all other cases, including but not limited to, ripening mangos, pears, tomatoes and citrus; setting fruit for pineapple; improving growth in bean sprouts, drying operations and sanitation procedures.

2. Restrictions to mitigate its harmful effects, as mentioned above should be included in the changes

I have no commercial or financial interest in ethylene. I have grown non commercial amounts of organic pineapple and have inspected farms that grow limited amounts of organic pineapple.

Reviewer 3
Organic crops are perceived by the public as being produced naturally and of a better quality than many crops produced by traditional agriculture. Unfortunately much of the commercially produced fruit in the United States is tasteless. This means that consumers expect something other than hard or mealy tomatoes and tasteless fruit when they purchase organic produce. They expect naturally ripened fruit. At the same time ethylene is naturally involved in fruit ripening.

Probably the most compatible method of ethylene use would be to use ripening fruit to generate ethylene in ripening rooms. Unfortunately at this time non-synthetic ethylene is not available. This means that a petroleum derived product is used for what in many cases is a question of produce cosmetics rather than a production necessity. Of the three uses, fruit ripening, bean sprout growth and pineapple flower induction, the latter is probably the most necessary. Overall, other than its production from petroleum feedstocks ethylene use does not appear environmentally damaging.

There was insufficient scientific, agronomic information provided in the TAP review package on the use of ethylene in pineapple production. Flowering and yield information on pineapples with and without ethylene treatment is important to determine if ethylene is really necessary. It appears the ethylene use in pineapples is more a question of economics and farm size rather than agronomic need. A separate, more complete review is recommended for ethylene use in pineapple flower induction. If calcium carbide/acetylene has not been reviewed for pineapple production it should be. It should not be addressed marginally only under a discussion of ethylene.

Not enough is known about this technique (ethanol method) to determine if it is synthetic or not. Generally ethanol dehydration to produce ethylene would use sulfuric acid and heat. This would result in a synthetic product. In addition the use of heat is questionable. Under the synthetic parameters provided to TAP reviewers the combustion of biologically derived materials is considered natural (such as wood ash). The combustion of minerals or non-biologically derived materials is considered synthetic. It has been stated to this reviewer on a separate occasion that heat applied exogenously to biological material was not permitted. This indicates that the use of heat has not yet been clearly addressed. Based on the above information this reviewer recommends that ethylene produced by heating to 360oF be considered synthetic at least until the issue of external heat is clarified.

It is recommended that the NOSB not prohibit non-synthetic ethylene for use in fruit ripening and bean sprout production. Synthetic sources should be prohibited. This recommendation is made recognizing there are no current non-synthetic ethylene sources available at this time.

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