



Anthropogenic and biogenic sources of Ethylene and the potential for human exposure: A literature review



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ARTICLE INFO

Article history:

Available online 19 August 2015

Keywords:

Personal exposure
Indoor
Outdoor
Microenvironment
Occupational
Community
Anthropogenic
Biogenic
Ethylene

ABSTRACT

This review examines available published information on ethylene emission sources, emission magnitudes, and inhalation exposures in order to assess those factors and circumstances that can affect human contact with this omnipresent gas. The results reveal that airborne ethylene concentrations at the ppb levels are commonplace and can arise in the vicinity of traffic corridors, forest fires, indoor kitchens, horticultural areas, oil fields, house fires, and petrochemical sites. The primary biogenic sources of ethylene derive from microbial activity in most soil and marine environments as well as its biological formation in wide variety of plant species. Sizable amounts of ethylene can also result from the burning of fossil fuels, forest and savanna fires, and crop residue combustion. Motor vehicle exhaust is the largest contributor to urban ethylene levels under most circumstances, but industrial flare releases and fugitive emissions may also be of relevance. Occupational exposures generally range up to about 50–100 ppm and have been documented for those working in the horticultural, petrochemical, and fire and rescue industries. Continuous personal monitoring at the community level has documented exposures of 3–4 ppb. These levels are more closely associated with the ethylene concentrations found indoors rather than outdoors indicating the importance of exposure sources found within the home. Indoor air sources of ethylene are associated with environmental tobacco smoke, wood or propane fuel use, fruit and vegetable storage, and cooking. Ethylene is not found in any consumer or commercial products and does not off-gas from building products to any appreciable extent. The review indicates that outdoor sources located some distance from the home do not make an appreciable contribution to personal exposures given the strength and variety of sources found in the immediate living environment.

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1. Introduction

Ethylene (ETH, CAS RN 75-84-1) is a ubiquitous industrial gas that is produced and used in very large quantities in the United States and elsewhere. ETH is also emitted by a wide variety of biogenic and anthropogenic sources so the opportunity for exposure is widespread. Despite these attributes there have been few formal or informal attempts at characterizing human inhalation exposure in different subpopulations. Although a tremendous amount of information is available on airborne concentrations under a variety of conditions, the data has not been compiled or assembled in a manner that allows a systematic examination of the overall burden from inhalation.

The purpose of this review is to examine what is known about community and occupational exposures to ETH in relation to known emission sources. The findings provide useful information for (i) segregating the sources of exposure; (ii) identifying the occupations where the highest exposures may occur; (iii) establishing potential microenvironmental factors affecting community level exposures; and (iv) constructing indoor or outdoor exposure models. Although a full literature search was performed in conjunction with this effort, space limitations only allow a small portion of this information to be presented. An attempt has been made to cull the hundreds of papers with usable source and concentration-related information and focus on those that provide a representative view.

2. Biogenic sources

The biogenic release of ETH can under some circumstances be substantial, but at the local level it can easily be overwhelmed by

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other sources such as traffic and biomass burning [1]. Traditional understanding holds that the emission of ETH from soil, vegetation, and marine water constitute the main biogenic sources; whereas the release from industrial sources, biomass burning, and traffic are the most important anthropogenic sources [2]. More recent evaluations, however, tend to segregate biomass burning as a separate classification, since it can arise both naturally or via human activity. The best current estimate of global ETH release to the atmosphere is 1.05 Tg per year (Tg/yr) from anthropogenic sources, 5.35 Tg/yr for biomass burning, and 2.7 Tg/yr from biogenic sources [3]. Since these estimates are based on information compiled in 1997 they are not reflective of the decline in traffic and industry-related emissions observed in recent years [4]. Wintertime background levels of ETH at different altitudes in the upper troposphere generally range from 2 to 50 ppt (2.3–57.4 ng/m³), but levels of 200 ppb (229.5 µg/m³) can be observed under some circumstances [5].

2.1. Vegetation

ETH is emitted by many types of vegetation including fruits and vegetables. In plants, it functions as a hormone that is responsible for the initiation and termination of many growth processes including fruit ripening, seed germination, inhibition of root and stem elongation, flowering, sex determination, and senescence [6]. Fruits, in particular, demonstrate a large increase in ETH production during maturation and ripening. Under normal conditions, the emission of ETH from the skin of fruits and vegetables such as red tomatoes, figs, pears, apples, kiwi, and yellow bananas ranged from 1.1 to 160 µL/m²-hr (0.04–7.18 µmol/m²-hr) [7]. In contrast, the range of emission rates for cherry tomatoes, bell peppers, cucumbers, and mandarin oranges was much lower at 60–890 nL/m²-hr (2.7–39.0 nmol/m²-hr). As would be expected, ETH is released in relatively large amounts during the storage of fruits and vegetables with peak production rates of 1–3 µg/kg-sec (128.3–385.0 µmol/kg-hr) for tomatoes or kiwi stored at 20 °C [8,9]. The average concentration of ETH at 2.5 m above a maize and soybean field has been shown to be 3.3 and 30.3 ppb (3.8 and 34.8 µg/m³), respectively [10]. These data underscore the important role of ETH in plant physiology and growth; however, it can also be harmful to many types of vegetation at higher concentrations [11].

The biogenic emission of ETH from vegetative sources can contribute to the atmospheric levels under some circumstances. Measurements of ETH release from a mid-latitude forest in Massachusetts showed that the levels in air during the summer months were higher during the day than at night and that the levels were not correlated with acetylene, which is a marker for exhaust emissions [12]. Using continuous measurements, the flux of ETH above the forest canopy was associated with incident solar radiation, which indicated a photosynthetic source. The average diurnal flux of ETH over a 5 month period lasting from June through October was 2.63×10^{10} mol/cm²-sec. These results are consistent with those from an independent study of ETH release above a ponderosa pine forest in California [13]. The mean daytime concentration of ETH during the month of July was found to be 311 ppt (0.4 µg/m³) and the levels were found to increase after sunrise.

The importance of biogenic release as a source for tropospheric ETH was confirmed in an early investigation that examined the relative contribution of natural and anthropogenic emissions [14]. The results found that on a global basis 18–45 million tons (16.3–40.8 Tg/yr) of ETH was released annually with natural sources accounting for 74%. The overall global release of ETH from biogenic sources was found to far outweigh the release from anthropogenic sources, the later estimated to be 9.19 million tons/yr (8.3 Tg/yr).

2.2. Soil, sediment, and tree litter

ETH can be produced and consumed by soil and leaf litter, but the relative rates of these two processes vary considerably depending on soil chemistry and environmental conditions. A wide variety of soil microorganisms are capable of generating ETH under anaerobic conditions [15]. In normally aerated soil, production will occur at localized microsites or rhizospheres that are situated in close vicinity to plant roots [16]. There is also evidence to suggest that soil fungi can produce ETH under aerobic conditions [17,18]. The rate of production is influenced by moisture content, temperature, organic matter, and pH, with sandy soil yielding higher evolution rates than clay or loam [19]. The production rate of ETH in 15 different types of desert soils ranged from 0.3 to 245 pmol/g-day (0.01–10.2 nmol/kg-hr) [20]. Soils with the highest organic carbon content generally produced the most ETH. ETH production factors of 0.2–11.0 ng/g-day (0.3–16.3 nmol/kg-hr) of soil were measured in air dried surface soil samples collected from 17 different types of grasslands [21]. Concentrations of approximately 3–5 ppm (3–6 mg/m³) have been measured in loamy soil with an oxygen tension of less than 8% [22]. Forest litter may also lead to the formation of ETH with the rates being much higher than for the underlying soil [23]. The rate of production in the top 3 cm of litter from a spruce forest ranged from 84 to 103 nmol/kg-hr in two different regions of the forest; whereas the level in the soil itself never exceeded 1 nmol/kg-hr. Even higher emissions were observed for the leaf litter from Cyprus trees with maximum release rates of 225–540 µmol/kg-hr observed after incubating the leaves with seawater for 24 days [24]. Studies with sequoia, rice, maize, cherry and beech leaf litter have shown that the release of ETH is strongly temperature dependent and unassociated with a specific enzymatic process [25]. The total global source strength of ETH from leaf litter was found to range from 0.01 to 0.22 Tg/yr for ground leaves and 0.01–0.48 Tg/yr for whole leaves.

ETH consumption by soil bacteria may at times outweigh soil production. ETH oxidation in soil is mediated by some species of aerobic bacteria that utilize ETH as a carbon and energy source [26]. Measurements in coniferous and deciduous forest soil yield conflicting results with ETH formation occasionally exceeding consumption rates depending on the soil type and the year of analysis [27]. This is not entirely unexpected, since the rates are dependent on the oxygen tension of the soil and the degree of water saturation. In general, however, production was found to exceed consumption rates in the soil from coniferous forests [28].

Marine sediments have also been shown to produce measurable amounts of ETH under laboratory conditions. The anoxic conditions in sediments may lead to the generation of appreciably greater amounts of ETH than soils. This sediment production will augment the ETH that is generated by marine organisms in the overlying water column. There have only been limited investigations of ETH production by freshwater sediments and they have not been found to be significant [27]. The measurement of ETH levels in twelve marine sediment samples collected off the Texas Gulf coast revealed concentrations ranging from 45 to 154 nL/L (57–194 ng/L) at core depths of 5–10 cm [29]. The levels did not change appreciably in serial 5 cm samples collected to depths of 170 cm. Similar levels were noted in sediment samples collected in the Bering Sea; however the water temperature in this location was much lower [30]. Measurements taken in sediment samples from the San Francisco Bay gave an average ETH value of 81 nL/L (102 ng/L) for core samples from the upper 10 cm of the sediment surface [31].

2.3. Marine sources

ETH is routinely detected in seawater, which is an acknowledged

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