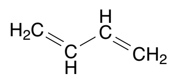
1,3-Butadiene

CAS No. 106-99-0

Known to be a human carcinogen

First listed in the *Fifth Annual Report on Carcinogens* (1989)



Carcinogenicity

1,3-Butadiene is *known to be a human carcinogen* based on sufficient evidence of carcinogenicity from studies in humans, including epidemiological and mechanistic studies. 1,3-Butadiene was first listed in the *Fifth Annual Report on Carcinogens* in 1989 as *reasonably anticipated to be a human carcinogen* based on sufficient evidence of carcinogenicity from studies in experimental animals. The listing was revised to *known to be a human carcinogen* in the *Ninth Report on Carcinogens* in 2000.

Cancer Studies in Humans

A number of epidemiological studies have shown an association between occupational exposure to 1,3-butadiene and excess mortality from cancer of the lymphatic and hematopoietic systems. These include (1) a cohort study showing increased risk of lymphosarcoma and reticulosarcoma in workers who manufactured 1,3-butadiene monomer, (2) a study of styrene-butadiene rubber workers in eight plants in the United States and Canada showing increased risk of leukemia among production workers, and (3) a case-control study within the cohort of styrene-butadiene rubber workers showing a large excess of leukemia associated with exposure to 1,3-butadiene and not to styrene (IARC 1992). In addition, an excess of lymphosarcoma and reticulosarcoma was found among 1,3-butadiene production workers in a previously unstudied chemical plant (Ward *et al.* 1996). Excess deaths from leukemia were observed among long-term workers who were hired before 1960 and had worked in the three (of eight studied) styrene-butadiene rubber plants with the highest exposure to butadiene (standardized mortality ratio = 1.8 in comparison with the U.S. population). A second case-control study of styrene-butadiene rubber workers with lymphopoietic cancer (with a new set of controls for each case) confirmed the strong association and significant dose-response relationship between 1,3-butadiene exposure score and risk of leukemia (Matanoski *et al.* 1993). Finally, a follow-up study of styrene-butadiene rubber workers in the synthetic rubber industry also found a dose-response relationship between 1,3-butadiene exposure level and the occurrence of leukemia (Delzell *et al.* 1996, 2006, Macaluso *et al.* 1996).

Studies on Mechanisms of Carcinogenesis

1,3-Butadiene appears to cause tumors in humans and rodents through its metabolism to DNA-reactive epoxide intermediates, which cause genetic alterations in proto-oncogenes or tumor-suppressor genes (Melnick and Kohn 1995). Mouse, rat, and human liver microsomes have been shown to oxidize 1,3-butadiene to epoxybutene (Csadany *et al.* 1992) and to further oxidize the monoepoxide to diepoxybutane (Seaton *et al.* 1995). These metabolites form N^7-alkylguanine adducts that have been detected in liver DNA of mice exposed to 1,3-butadiene and in the urine of a worker exposed to 1,3-butadiene. Activated K-*ras* oncogenes and inactivated tumor-suppressor genes observed in 1,3-butadiene-induced tumors in mice are analogous to genetic alterations frequently observed in a wide variety of human cancers. Dose-related increases in *hprt* mutations have been observed in lymphocytes isolated from mice exposed to 1,3-butadiene or its epoxide metabolites and in occupationally exposed workers. The mutational spectra for 1,3-butadiene and its epoxide metabolites at the *hprt* locus in mouse lymphocytes are similar to the mutational spectrum for ethylene oxide, an alkylating agent listed in the Report on Carcinogens as *known to be a human carcinogen.*

Cancer Studies in Experimental Animals

There is sufficient evidence for the carcinogenicity of 1,3-butadiene from studies in experimental animals. Inhalation exposure to 1,3-butadiene caused benign or malignant tumors at several different tissue sites in rodents, including the hematopoietic system, heart (hemangiosarcoma), lung, forestomach, Harderian gland, preputial gland, liver, mammary gland, ovary, and kidney in mice (NTP 1984, Huff *et al.* 1985, Melnick *et al.* 1990) and the pancreas, testis, thyroid gland, mammary gland, uterus, and Zymbal gland in rats (Owen *et al.* 1987).

Properties

1,3-Butadiene is an olefin which at room temperature is a colorless gas with a mild aromatic or gasoline odor. It is insoluble in water but soluble in ether, ethanol, acetone, and other organic solvents. It polymerizes readily, especially in the presence of oxygen; therefore, it is shipped and stored with an inhibitor to prevent this reaction (Akron 2009). It is also a dangerous fire hazard. Physical and chemical properties of 1,3-butadiene are listed in the following table.

Property	Information
Molecular weight	54.1[a]
Density	0.6149 g/cm^3 at 25°C[a]
Melting point	–108.966°C[a]
Boiling point	–4.5°C at 760 mm Hg[a]
Log K_{ow}	1.99[b]
Water solubility	0.735 g/L at 20°C[a]
Vapor pressure	2,110 mm Hg at 25°C[a]
Vapor density relative to air	1.87[a]

Sources: [a]HSDB 2009, [b]ChemIDplus 2009.

Use

1,3-Butadiene is used primarily as a monomer to manufacture many different types of polymers and copolymers and as a chemical intermediate to produce a number of important industrial chemicals. More than 75% of the 1,3-butadiene produced goes into synthetic rubber products (CEN 1986). The major uses include production of styrene-butadiene rubber (30% to 35%), polybutadiene rubber (20% to 22%), adiponitrile (12% to 15%), styrene-butadiene latex (10%), neoprene rubber (5% to 6%), acrylonitrile-butadiene-styrene resins (5% to 6%), and nitrile rubber (3%), exports (4%), and other uses, including production of specialty polymers (2% to 8%) (IARC 1992, ATSDR 1993). The major end-use products containing styrene-butadiene and polybutadiene are tires. Other products include latex adhesives, seals, hoses, gaskets, various rubber products, nylon carpet backings, paper coatings, paints, pipes, conduits, appliance and electrical equipment components, automotive parts, and luggage. The only major nonpolymer use is in the manufacture of adiponitrile, a nylon intermediate. Butadiene is also used in the manufacture of the fungicides captan and captafol (Morrow 1990, IARC 1992, Kirschner 1996).

Production

1,3-Butadiene is isolated by distillation or extraction from crude butadiene, which is a by-product of ethylene production. Commercial production began in the 1930s (IARC 1992). Between 1980 and 2002, annual U.S. production of rubber-grade 1,3-butadiene ranged from a low of 869,000 metric tons (1.9 billion pounds) in 1982 to a high of 2,009,000 metric tons (4.4 billion pounds) in 2000 (IARC 1992, CEN 1999, 2003). The average annual change was about 2.5% from 1992 to 2002 compared with about 1.2% from 1980 to 1990. 1,3-Butadiene ranked 34th among the top 50 chemical commodities produced in the United States in 1987, falling to 36th by the mid 1990s (Morrow 1990, Kirschner 1996, CEN 1997). In 1990, 30 ethylene plants in the United States produced crude butadiene streams that were processed in 11 extraction plants (Morrow 1990). In 2009, 11 U.S. producers and 12 U.S. suppliers of 1,3-butadiene were identified (ChemSources 2009, SRI 2009). Because U.S. demand for 1,3-butadiene has exceeded the domestic supply in most years, imports have greatly exceeded exports. Annual U.S. imports ranged from 500 million to 900 million pounds from the late 1970s to the mid 1980s and from 1.2 billion to 1.4 billion pounds from 1998 to 2000, decreasing to 200 million pounds in 2002 (ATSDR 1993, USITC 2009). In 2008, imports were 1.7 billion pounds. Annual U.S. exports ranged from 94 million to 145 million pounds from the late 1970s through the mid 1980s, decreasing to 37.6 million pounds in 2000 and 15.2 million pounds in 2002. In 2008, exports were 217.6 million pounds.

Exposure

The primary route of potential exposure to 1,3-butadiene for the general population is inhalation. Some exposure may occur through ingestion of contaminated food or water or dermal contact; however, these routes of exposure are unlikely under most circumstances. 1,3-Butadiene is not a common contaminant of water supplies. Although some food packaging contains residual 1,3-butadiene, the available data indicate that it does not usually migrate to the food. Certain cooking oils, such as rapeseed oil (canola), release 1,3-butadiene when heated (Shields *et al.* 1995).

Most people are exposed to low levels of 1,3-butadiene in the air, because it is released to the environment during its production, use, storage, and disposal and is present in gasoline, automobile exhausts, and cigarette smoke. 1,3-Butadiene is emitted from petroleum refineries and from furnaces at secondary lead smelting facilities handling automotive lead-acid batteries that contain plastic battery separators or that have hard rubber casings (EPA 1996). Incomplete combustion of a variety of fuels forms 1,3-butadiene as a product. 1,3-Butadiene makes up 0.5% to 2% of the total organic gas emissions from most types of combustion (Ligocki *et al.* 1994). It can also be found in motor-vehicle exhaust emissions as a product of incomplete combustion of gasoline and diesel oil and from the thermal breakdown of plastics (ATSDR 1993, EPA 1996). Through modeling of dispersion from a typical freeway source in California, it was estimated that gasoline-fueled vehicles emit 0.011 g of 1,3-butadiene per mile (Cooper and Reisman 1992). 1,3-Butadiene also is formed naturally as a by-product of forest fires (HSDB 2009). Releases of 1,3-butadiene in sidestream cigarette smoke into the air have been variously estimated at 152 to 400 μg per cigarette (Ligocki *et al.* 1995). Calculations based on 400 μg per cigarette indicate that 1,3-butadiene concentrations in the homes of smokers would be increased by approximately 4 $\mu g/m^3$, and concentrations in air at workplaces allowing smoking would be increased by 13 $\mu g/m^3$ (Wallace 1991).

According to the U.S. Environmental Protection Agency's Toxics Release Inventory, total industrial environmental releases of 1,3-butadiene declined from more than 7.7 million pounds in 1988 to about 1.8 million pounds in 2007, of which over 90% was released to air (TRI 2009). However, a nationwide 1,3-butadiene inventory (including vehicle emissions and emissions from manufacturing and producing facilities) calculated annual butadiene emissions to air to be 102 million kilograms (225 million pounds) in 1990 (Ligocki *et al.* 1994), considerably higher than EPA's estimate of about 5.2 million pounds (2.4 million kilograms) for industrial emissions in the same year.

The median daily concentrations of 1,3-butadiene in U.S. ambient air samples collected from 1970 to 1987 were 0.29 ppb in urban areas (385 samples), 0.32 ppb in suburban areas (196 samples), and 0.1 ppb in rural areas (2 samples). The maximum 24-hour average concentrations of 1,3-butadiene reported for four U.S. cities in 2004 were 0.3 ppb for St. Louis, Missouri, 0.5 ppb for Chicago, Illinois, and Los Angeles, California, and 37.4 ppb for Houston, Texas (Clements *et al.* 2006). However, reported average daily concentrations of 1,3-butadiene in ambient air within a mile of petrochemical facilities have exceeded 100 ppb, and the highest hourly average concentrations have exceeded 900 ppb (ATSDR 1993). Volatilization of 1,3-butadiene from wastewaters of styrene-1,3-butadiene copolymer production at publicly owned treatment works has been calculated to be 21 tons per year (EPA 1996).

Occupational exposure to 1,3-butadiene may occur through inhalation and, to a lesser extent, dermal contact (NTP 1984). The National Occupational Exposure Survey (conducted from 1981 to 1983) estimated that about 52,000 workers at 2,201 facilities, including 1,410 women, potentially were exposed to 1,3-butadiene (NIOSH 1990). This estimate does not include workers exposed to butadiene polymers and copolymers and is consistent with an earlier an estimate of about 66,000 to 70,000 workers at 3,086 facilities reported in the National Occupational Hazard Survey (conducted from 1972 to 1974) (NIOSH 1976). Health hazard evaluation surveys conducted by the National Institute for Occupational Safety and Health at six facilities found air concentrations of 1,3-butadiene ranging from 0.06 to 39 ppm. Surveys conducted at many monomer, polymer, and end-user plants have reported concentrations ranging from below detection to 374 ppm (827 mg/m^3). In most cases, 8-hour time-weighted-average concentrations were less than 10 ppm (< 22 mg/m^3) (IARC 1992, ATSDR 1993). For the monomer industry as a whole, 1,3-butadiene concentrations were greater than 10 ppm (> 22 mg/m^3) in 7.1% of the samples, 2 to 10 ppm (4 to 22 mg/m^3) in 12.8%, 1 to 2 ppm (2 to 4 mg/m^3) in 12.3% and less than 1 ppm (< 2 mg/m^3) in 67.8%. The Occupational Safety and Health Administration permissible exposure limit is 1 ppm. For the polymer industry as a whole, the corresponding percentages for these four ranges were 3.3%, 7.7%, 3.3%, and 85.8%, respectively. The arithmetic mean exposure for personal full-shift exposures in the polymer plants was 1.14 ppm (2.57 mg/m^3) (Fajen *et al.* 1993).

Regulations

Department of Transportation (DOT)

Butadienes are considered hazardous materials, and special requirements have been set for marking, labeling, and transporting these materials.

Environmental Protection Agency (EPA)

Clean Air Act

Mobile Source Air Toxics: Listed as a mobile source air toxic for which regulations are to be developed.
National Emissions Standards for Hazardous Air Pollutants: Listed as a hazardous air pollutant.
New Source Performance Standards: Manufacture of 1,3-butadiene is subject to certain provisions for the control of volatile organic compound emissions.
Prevention of Accidental Release: Threshold quantity (TQ) = 10,000 lb.
Urban Air Toxics Strategy: Identified as one of 33 hazardous air pollutants that present the greatest threat to public health in urban areas.
Standards have been established for emissions of 1,3-butadiene from reformulated gasoline and motor vehicles.

Comprehensive Environmental Response, Compensation, and Liability Act

Reportable quantity (RQ) = 10 lb.

Emergency Planning and Community Right-To-Know Act

Toxics Release Inventory: Listed substance subject to reporting requirements.

Occupational Safety and Health Administration (OSHA)

While this section accurately identifies OSHA's legally enforceable PELs for this substance in 2010, specific PELs may not reflect the more current studies and may not adequately protect workers.

Permissible exposure limit (PEL) = 1 ppm.

Short-term exposure limit (STEL) = 5 ppm.

Comprehensive standards for occupational exposure to 1,3-butadiene have been developed.

Guidelines

American Conference of Governmental Industrial Hygienists (ACGIH)

Threshold limit value – time-weighted average (TLV-TWA) = 2 ppm.

National Institute for Occupational Safety and Health (NIOSH)

Immediately dangerous to life and health (IDLH) limit = 2,000 ppm.

Listed as a potential occupational carcinogen.

References

Akron. 2009. *The Chemical Database*. The Department of Chemistry at the University of Akron. http://ull.chemistry.uakron.edu/erd and search on CAS number. Last accessed: 10/20/09.

ATSDR. 1993. *Toxicological Profile for 1,3-Butadiene*. NTIS Accession No. PB93-110690. Atlanta, GA: Agency for Toxic Substances and Disease Registry. 135 pp.

CEN. 1986. Key Chemicals. Butadiene. *Chem Eng News* 64(23): 15.

CEN. 1997. Production: Mixed in 1996. *Chem Eng News* 75(25): 40-45.

CEN. 1999. Production. Modest gain. *Chem Eng News* 77(26): 34-39.

CEN. 2003. Production inches up in most countries. *Chem Eng News* 81(27): 51-61.

ChemIDplus. 2009. *ChemIDplus Advanced*. National Library of Medicine. http://chem.sis.nlm.nih.gov/chemidplus/chemidheavy.jsp and select Registry Number and search on CAS number. Last accessed: 10/20/09.

ChemSources. 2009. *Chem Sources - Chemical Search.* Chemical Sources International. http://www.chemsources.com/chemonline.html and search on butadiene. Last accessed: 10/20/09.

Clements AL, Flatt VB, Fraser MP, Hamilton WJ, Ledvina PS, Mathur SK, Tamhane A, Ward JB. 2006. *The Control of Air Toxics: Toxicology Motivation and Houston Implications*. Rice University Department of Civil and Environmental Engineering. http://hydrology.rice.edu/ceve/fraser/FINAL%20MASTER.pdf.

Cooper FI, Reisman JI. 1992. The air toxic problem in California: A summary of CARB, BAAQMD and SCAQMD ambient air monitoring data. *Proc Ann Meet Air Waste Manage Assoc* 13: 9.

Csadany GA, Guengerich FP, Bond JA. 1992. Comparison of the biotransformation of 1,3-butadiene in rodents and man: Blood concentrations of 1,3-butadiene, its metabolically formed epoxides and of haemoglobin adducts—relevance of gluthathione depletion. *Toxicology* 113: 300-305.

Delzell E, Sathiakumar N, Hovinga M, Macaluso M, Julian J, Larson R, Cole P, Muir DC. 1996. A follow-up study of synthetic rubber workers. *Toxicology* 113(1-3): 182-189.

Delzell E, Sathiakumar N, Graff J, Macaluso M, Maldonado G, Matthews R. 2006. An updated study of mortality among North American synthetic rubber industry workers. *Res Rep Health Eff Inst* 132: 1-63.

EPA. 1996. *Locating and Estimating Air Emissions from Sources of 1,3-Butadiene*. Technical Report No. EPA-454/R-96-008. Research Triangle Park, NC: U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards. 251 pp.

Fajen JM, Lunsford RA, Roberts DR. 1993. Industrial exposure to 1,3-butadiene in monomer, polymer and end-user industries. *IARC Sci Publ* (127): 3-13.

HSDB. 2009. *Hazardous Substances Data Bank*. National Library of Medicine. Last updated: 8/29/03. http://toxnet.nlm.nih.gov/cgi-bin/sis/htmlgen?HSDB and search on CAS number. Last accessed: 10/20/09.

Huff JE, Melnick RL, Solleveld HA, Haseman JK, Powers M, Miller RA. 1985. Multiple organ carcinogenicity of 1,3-butadiene in B6C3F$_1$ mice after 60 weeks of inhalation exposure. *Science* 227(4686): 548-549.

IARC. 1992. 1,3-Butadiene. In *Occupational Exposures to Mists and Vapours from Strong Inorganic Acids and Other Industrial Chemicals*. IARC Monographs on the Evaluation of Carcinogenic Risk of Chemicals to Humans, vol. 54. Lyon, France: International Agency for Research on Cancer. pp. 237-285.

Kirschner EM. 1996. Growth of top 50 chemicals slowed in 1995 from very high 1994 rate. *Chem Eng News* 74(15): 16-18, 20, 22.

Ligocki MP, Fieber JL, Ball JC, Pezda SA, Heuss JM, Paul RT, Wimette HJ. 1994. Projected emission trends and exposure issues for 1,3-butadiene. *Proc Annu Meet Air Waste Manage Assoc* 4B: 18.

Ligocki MP, Gardner L, Tunggal HH, Heiken JG, Atkinson RD, Axelrad D. 1995. Cumulative exposure to air toxics: indoor sources. *Proc Annu Meet Air Waste Manage Assoc* 3A: 16.

Macaluso M, Larson R, Delzell E, Sathiakumar N, Hovinga M, Julian J, Muir D, Cole P. 1996. Leukemia and cumulative exposure to butadiene, styrene and benzene among workers in the synthetic rubber industry. *Toxicology* 113(1-3): 190-202.

Matanoski G, Francis M, Correa-Villasenor A, Elliott E, Santos-Burgoa C, Schwartz L. 1993. Cancer epidemiology among styrene-butadiene rubber workers. *IARC Sci Publ* (127): 363-374.

Melnick RL, Huff J, Chou BJ, Miller RA. 1990. Carcinogenicity of 1,3-butadiene in C57BL/6 x C3H F$_1$ mice at low exposure concentrations. *Cancer Res* 50(20): 6592-6599.

Melnick RL, Kohn MC. 1995. Mechanistic data indicate that 1,3-butadiene is a human carcinogen. *Carcinogenesis* 16(2): 157-163.

Morrow NL. 1990. The industrial production and use of 1,3-butadiene. *Environ Health Perspect* 86: 7-8.

NIOSH. 1976. *National Occupational Hazard Survey (1972-74)*. DHEW (NIOSH) Publication No. 78-114. Cincinnati, OH: National Institute for Occupational Safety and Health.

NIOSH. 1990. *National Occupational Exposure Survey (1981-83)*. National Institute for Occupational Safety and Health. Last updated: 7/1/90. http://www.cdc.gov/noes/noes1/13410sic.html.

NTP. 1984. *Toxicology and Carcinogenesis Studies of 1,3-Butadiene (CAS No. 106-99-0) in B6C3F$_1$ Mice (Inhalation Studies)*. Technical Report Series no. 288. NIH Publication no. 84-2544. Research Triangle Park, NC: National Toxicology Program. 111 pp.

Owen PE, Glaister JR, Gaunt IF, Pullinger DH. 1987. Inhalation toxicity studies with 1,3-butadiene. 3. Two year toxicity/carcinogenicity study in rats. *Am Ind Hyg Assoc J* 48(5): 407-413.

Seaton MJ, Follansbee MH, Bond JA. 1995. Oxidation of 1,2-epoxy-3-butene to 1,2:3,4-diepoxybutane by cDNA-expressed human cytochromes P450 2E1 and 3A4 and human, mouse and rat liver microsomes. *Carcinogenesis* 16(10): 2287-2293.

Shields PG, Xu GX, Blot WJ, Fraumeni JF Jr, Trivers GE, Pellizzari ED, Qu YH, Gao YT, Harris CC. 1995. Mutagens from heated Chinese and U.S. cooking oils. *J Natl Cancer Inst* 87(11): 836-841.

SRI. 2009. *Directory of Chemical Producers*. Menlo Park, CA: SRI Consulting. Database edition. Last accessed: 10/20/09

TRI. 2009. *TRI Explorer Chemical Report.* U.S. Environmental Protection Agency. http://www.epa.gov/triexplorer and select 1,3-Butadiene.

USITC. 2009. *USITC Interactive Tariff and Trade DataWeb.* United States International Trade Commission. http://dataweb.usitc.gov/scripts/user_set.asp and search on HTS no. 2901241000. Last accessed: 10/20/09.

Wallace, LA. 1991. Comparison of risks from outdoor and indoor exposure to toxic chemicals. *Environ Health Perspect* 95: 7-13.

Ward EM, Fajen JM, Ruder AM, Rinsky RA, Halperin WE, Fessler-Flesch CA. 1996. Mortality study of workers employed in 1,3-butadiene production units identified from a large chemical workers cohort. *Toxicology* 113(1-3): 157-168.