



2016 Minerals Yearbook

BROMINE [ADVANCE RELEASE]

BROMINE

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The United States was one of four leading bromine producers in the world along with China, Israel, and Jordan. World production of bromine in 2016, excluding the United States, was estimated to be 345,000 metric tons (t) compared with 301,000 t in 2015 (tables 1, 6). In 2016, bromine sold or used in the United States decreased compared with 2015, but data were withheld to avoid disclosing company proprietary information.

Bromine is one of two elements that are liquid at room temperature and is found principally as a dissolved species in seawater, evaporitic (salt) lakes, and underground brines associated with petroleum deposits. In addition, bromine is an essential element for life and is a requirement for tissue development (McCall and others, 2014). The primary uses for bromine compounds include, in descending order, brominated flame retardants (BFRs), intermediates and industrial uses, drilling fluids, and water treatment.

Production

Domestic production data for bromine were developed by the U.S. Geological Survey (USGS) from a voluntary canvass of the two U.S. producers—Albemarle Corp. and Chemtura Corp., both of which responded to the survey, representing 100% of total production. Production data collected by the USGS were withheld to avoid disclosing proprietary information, but capacity data for both producers were provided (table 2). In September, Lanxess AG (Cologne, Germany) announced it would be acquiring Chemtura in 2017, pending shareholder and regulatory approvals (Lanxess AG, 2016).

In the United States, bromine was recovered from brine wells in Arkansas, where bromine is found in the Jurassic Smackover Formation at a depth of about 2,400 meters (Arkansas Geological Survey, undated). The brines in Arkansas have bromine concentrations ranging from 3,000 to 5,000 parts per million (ppm) bromine; by comparison, seawater contains about 65 ppm bromine (Arkansas Geological Survey, undated; Mills and others, 2015, p. 2).

After bromine processing, the spent brine is returned underground into the production formation by class V injection wells that are regulated by the U.S. Environmental Protection Agency (EPA). The chemical composition of the spent brine is generally similar to that of the original, except that the concentration of the target elements (such as bromine and magnesium) is reduced and the concentration of other elements (such as calcium) may have increased through substitution (U.S. Environmental Protection Agency, 1999, p. 1–2, 5).

Environment

Methyl bromide, a broad-spectrum pesticide used in the control of nematodes, pathogens, pest insects, rodents, and weeds, is the leading bromine-containing pesticide in the world,

but its use has been declining owing to the ban imposed by the Montreal Protocol, which classified it as a class I ozone-depleting substance. As part of the Montreal Protocol, developed countries were to stop using the pesticide by 2005; however, the United States has received annual exemptions for crops and other critical uses. The critical-use exemption is for applications where no technically or economically feasible alternatives to methyl bromide exist. For 2016, the EPA authorized use of 235 t, less than 1% of the historic 1991 baseline consumption of methyl bromide, for approved critical uses (U.S. Environmental Protection Agency, 2015, p. 61988). This was a decrease from the 2015 authorized use of 377 t (U.S. Environmental Protection Agency, 2014, p. 44305). Use of methyl bromide was also allowed through a quarantine and preshipment exemption for agricultural commodities and lumber. Methyl bromide has proven to be difficult to replace because of its low cost and usefulness against a large variety of agricultural pests. Alternatives to methyl bromide exist but vary by the benefits needed for a particular crop. The U.S. Department of Agriculture has funded research regarding environmentally, technically, and economically feasible alternatives in California and Florida, where the majority of U.S. methyl bromide is used, and continues to fund this ongoing research initiative (Meadows, 2013; U.S. Department of Agriculture, 2016).

Recycling

Some bromide solutions were recycled to obtain elemental bromine and to prevent the solutions from being disposed of as hazardous waste. Hydrogen bromide is emitted as a byproduct of many organic reactions such as the reaction between an alkane and bromine (Weizmann Institute of Science, undated, p. 173). This byproduct can be recycled with virgin bromine brines and used as a source of bromine production. About 45% of Albemarle Corp.'s production is from recycled or byproduct bromides (Albemarle Corp., 2017, p. 68).

Bromine contained in plastics, such as BFRs, can be safely incinerated as a solid organic waste, and the bromine can be recovered (Mills and others, 2015, p. 12). Additionally, the stability of BFRs reduces or eliminates the need for incorporating additional flame retardants to new products made from recycled plastics, which had previously contained a BFR (Bromine Science and Environmental Forum, undated).

Consumption

The USGS did not collect consumption data on bromine compounds. Apparent consumption of bromine in the United States, calculated by the USGS as production plus imports minus exports, decreased in 2016. In 2016, the leading global applications of bromine were for the production of BFRs (41%), intermediates and industrial uses (30%), clear brine

fluids (16%), and water treatment (7%) (Israel Chemicals Ltd., 2017, p. 76).

BFRs are commonly used in many household and industrial appliances; electronic equipment, such as cases for computers, mobile telephones, and televisions; and other items, such as furniture, insulation boards, mattresses, and textiles. About 90% of all electrical components contain BFRs.

Bromine compounds are widely used in the agricultural, chemical, and pharmaceutical industries. Applications include dyes, perfumes, photographic chemicals, and zinc-bromine batteries. In particular, bromide compounds are especially effective pesticides, used as soil fumigants in agriculture, particularly in fruit growing, and as fumigants to prevent pests from attacking stored grain and fresh produce. World trade in agricultural goods depends on the use of bromine compounds to ensure compliance with mandatory quarantine rules.

Calcium bromide, sodium bromide, and zinc bromide, collectively referred to as clear brine fluids, are used in the oil- and gas-well-drilling industry for high-density, solids-free completion, packer, and workover fluids to reduce the likelihood of damage to the well bore and productive zone. These high-density fluids also help to prevent migration of fluids between underground formations through the well bore.

Another major use of bromine is as a water purifier and disinfectant, as an alternative to chlorine. Brominated compounds are used for water treatment in hot tubs and swimming pools and to control algae and bacterial growth in industrial processes.

Bromine and bromine compounds are also used to remove mercury from flue gas emissions at coal-fired electric powerplants (Vosteen and others, 2005). Inorganic bromine compounds, such as calcium bromide, when mixed with coal at powerplants, react with mercury in combustion zones, forming mercury compounds that are captured in scrubbers, removing up to 90% of mercury liberated during combustion (Fielding, 2012). Southern Research Institute (Birmingham, AL) developed a system that converts calcium bromide to bromine gas. The bromine gas then reacts with mercury in coal-fired powerplant flue gas to form mercuric bromide, which is captured and retained in the powerplant's wet scrubbers (Southern Research Institute, 2010).

Transportation

Bromine is transported in bulk quantities in the United States in 7,570- and 15,140-liter (L) lead-lined pressure tank railcars or in 6,435- to 6,813-L nickel-clad pressure tank trailers. The trailers must be at least 92% full to prevent inertia effects of the heavy liquid while on the highway. Dry nitrogen gas is recommended for use in pressurizing bromine during transfer, although dry air may be used. The gas used must be absolutely dry or severe corrosion results. When exposed to a high-humidity atmosphere, the water content of bromine can exceed 300 ppm. If the water content exceeds 70 ppm, the corrosiveness of bromine to many metals increases (Frim and Ukeles, 2007).

Prices

The price for purified, bulk, 99.95% bromine on an ex-works U.S. basis, as reported by Industrial Minerals, ranged from

\$2.00 to \$2.45 per pound (about \$4,400 to \$5,400 per metric ton) in 2016. Actual prices for bromine are negotiated on long- and short-term contracts between buyers and sellers.

Foreign Trade

In terms of bromine content, exports of bromine and bromine compounds in 2016 increased slightly compared with those in 2015 (table 3). The leading exported bromine compound in 2016 was methyl bromide, a broad-spectrum pesticide, whose use has been declining owing to its classification as an ozone-depleting substance. The amount of methyl bromide exported (13,600 t) in 2016 was almost double the amount exported in 2015. Mexico was the leading recipient of methyl bromide, receiving 82% of the total amount of methyl bromide exported by the United States in 2016 and 65% of the total amount of methyl bromide exported by the United States in 2015. The combined amount of calcium bromide and sodium bromide (5,700 t) exported in 2016 decreased by 57% compared with that exported in 2015. The decrease in exports of these compounds, which are commonly used as drilling fluids in the oil- and gas-well-drilling industry, mirrored the global decrease in drilling in 2016 (Baker Hughes Inc., 2017).

Imports of bromine and bromine compounds increased slightly during the same period, with a slight decrease in value compared with that in 2015 (table 4). The combined category of ammonium, calcium, and zinc bromide remained the dominant imported bromine product, in terms of quantity, accounting for 72% of imported materials in 2016. Israel was the leading supplier of ammonium, calcium, and zinc bromide, accounting for 96% of the total amount imported into the United States in 2016.

World Review

In 2016, China, Israel, Jordan, and the United States led in bromine production capacity globally (tables 2, 5). However, actual production was not necessarily proportional to capacity (tables 5, 6).

China.—In China, bromine operations were located in Shandong Province. Although the Shandong Provincial government and the Government of China require companies to purchase licenses for the extraction of bromine, many small unlicensed facilities continued to operate (Gulf Resources, Inc., 2017, p. 11).

Because bromine production capacity was available for only one company, estimated production listed in table 6 is higher than the capacity listed in table 5. Gulf Resources, Inc., one of the leading bromine producers in China, had a combined production capacity of about 47,300 metric tons per year (table 5). In 2016, Gulf Resources produced approximately 17,000 t of bromine, a 10% decrease compared with 2015 production of approximately 18,900 t (Gulf Resources, Inc., 2017, p. 45). Although its production and sales decreased in 2016, Gulf Resources did have an increase in net revenue from its bromine operations owing to a 20% increase in its sales price. The decrease in bromine sales volume was attributed to a slowdown in the Chinese economy (Gulf Resources, Inc., 2017, p. 42).

Israel.—Israel Chemicals Ltd. (ICL) (Tel Aviv) remained a world leader in bromine production with a maximum annual

production capacity of 280,000 t at operations on the Dead Sea (table 5). In 2016, ICL produced 162,000 t of elemental bromine compared with 116,000 t produced in 2015 (table 6) (Israel Chemicals Ltd., 2016, p. 45; 2017, p. 80). Production in 2015 was lower than in recent years owing to a workers' strike in Israel, which affected ICL's production during the first half of 2015 (Israel Chemicals Ltd., 2016, p. 45).

Jordan.—Jordan produced an estimated 100,000 t of bromine in 2016 (table 6). Jordan Bromine Co. Ltd. (a joint venture between Albemarle and Arab Potash Co.) processed brines from the Dead Sea in Safi, Jordan.

Outlook

Because of domestic and international fire safety standards regulating the flammability of construction, home furnishing, and electronic products, BFRs account for the largest consumption of bromine worldwide. Domestic and global consumption of BFRs is expected to follow trends in the construction and electronics markets. Environmental and toxicological concerns regarding some BFRs continued to be assessed in 2016. Questions of balancing fire safety with environmental and human health, in relation to BFRs, will likely continue to be examined in coming years.

Bromine use in clear brine drilling fluids is dependent on fluctuations in the business cycle for the oil- and gas-well-drilling industry. In 2016, weak demand for clear brine fluids used in offshore drilling reflected the continued decline in the average number of active drilling rigs worldwide (Baker Hughes Inc., 2017; Chemtura Corp., 2017, p. 31). Future bromine use in clear brine drilling fluids will continue to be dependent on fluctuations in the oil- and gas-well-drilling industry. However, long-term growth in the use of clear brine fluids for offshore natural-gas and oil drilling is expected (Albemarle Corp., 2017, p. 76).

Bromine and bromine compounds are highly effective at removing mercury from flue-gas emissions at coal-fired electric powerplants, and this is an area of potential growth for the industry. Using bromide compounds for abatement of mercury emissions appears to be more cost effective compared with other materials, such as chlorine-, fluorine-, or iodine-based compounds. The EPA's findings on its Mercury and Air Toxics Standards (MATS), which finalized standards for the reduction of air pollution from coal- and oil-fired powerplants, will likely initiate a growing market for bromine compounds as companies comply with these regulations (U.S. Environmental Protection Agency, 2016).

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TABLE 1
SALIENT BROMINE STATISTICS¹

(Metric tons and thousand dollars)

	2012	2013	2014	2015	2016
United States:					
Bromine sold or used: ²					
Quantity	W	W	W	W	W
Value	W	W	W	W	W
Exports: ^{3,4}					
Quantity (Br equivalent)	13,000	18,200	20,600	25,000	25,100
Value	48,600	61,200	67,100	79,700 ^r	80,900
Imports for consumption: ^{4,5}					
Quantity (Br equivalent)	53,300 ^r	36,300	57,600 ^r	58,000	58,100
Value	120,000	88,000	118,000	124,000	122,000
Apparent consumption	W	W	W	W	W
World, production ^{6,6}	422,000 ^r	389,000	375,000 ^r	301,000 ^r	345,000

^rEstimated. ^rRevised. W Withheld to avoid disclosing company proprietary data.

¹Table includes data available through June 29, 2017. Data are rounded to no more than three significant digits.

²Elemental bromine sold as such to nonproducers, including exports, or used by primary U.S. producers in preparing bromine compounds.

³Export values are free alongside ship.

⁴Source: U.S. Census Bureau and PIERS.

⁵Import values are cost, insurance, and freight.

⁶Does not include U.S. production.

TABLE 2
ELEMENTAL-BROMINE-PRODUCING PLANTS IN THE UNITED STATES IN 2016¹

State and company	County	Plant	Production source	Capacity ² (thousand metric tons)
Arkansas:				
Albemarle Corp.	Columbia	Magnolia South	Well brines	NA
Do.	do.	Magnolia West	do.	NA
Do.	Union	Satellite plants	do.	NA
Total				148 ³
Chemtura Corp.	do.	El Dorado Central and El Dorado South	do.	71 ⁴
Do.	do.	Marysville West	do.	59
Grand total				278

Do., do. Ditto. NA Not available.

¹Table includes data available through June 29, 2017.

²Actual production capacity is limited by brine availability.

³Total capacity of Magnolia South, Magnolia West, and Satellite plants.

⁴Total capacity of El Dorado Central and El Dorado South plants.

TABLE 3
U.S. EXPORTS OF BROMINE AND BROMINE COMPOUNDS¹

Compound	HTS ² code	2015			2016			Principal recipients in 2016
		Gross weight (metric tons)	Br equivalent (metric tons)	Value ³ (thousands)	Gross weight (metric tons)	Br equivalent (metric tons)	Value ³ (thousands)	
Elemental bromine	2801.30.2000	3,960	3,960	\$8,850	5,330	5,330	\$13,400	China, 59%; Canada, 28%; Belgium, 7%.
Inorganic bromine compounds:								
Calcium bromide ⁴	2827.59.2500	11,300	9,030	27,700	2,810	2,250	6,900	Trinidad and Tobago, 29%; United Arab Emirates, 22%; United Kingdom, 20%.
Potassium bromide ^{4,5}	2827.51.0000	13	9	23	10	7	17	Republic of Korea, 97%.
Sodium bromide ^{4,5}	2827.51.0000	5,570	4,330	9,750	4,440	3,450	7,770	Trinidad and Tobago, 59%; United Kingdom, 17%; Angola, 16%.
Organic bromine compounds:								
Ethylene dibromide	2903.31.0000	685	583 ^r	4,130	628	534	4,260	Belgium, 99%.
Methyl bromide	2903.39.1520	8,430 ^r	7,090 ^r	29,300 ^r	16,100	13,600	48,500	Mexico, 82%.
Total		30,000	25,000	79,700 ^r	29,300	25,100	80,900	

^rRevised.

¹Table includes data available through June 29, 2017. Data are rounded to no more than three significant digits; may not add to totals shown.

²Harmonized Tariff Schedule of the United States.

³Declared cost, insurance, and freight valuation exports are free alongside ship.

⁴Source: PIERS.

⁵Potassium bromide and sodium bromide import data are reported under a common HTS code.

Source: U.S. Census Bureau.

TABLE 4
U.S. IMPORTS OF BROMINE AND BROMINE COMPOUNDS¹

Compound	HTS ² code	2015			2016			Principal sources in 2016
		Gross weight (metric tons)	Br equivalent (metric tons)	Value ³ (thousands)	Gross weight (metric tons)	Br equivalent (metric tons)	Value ³ (thousands)	
Elemental bromine	2801.30.2000	2,530	2,530	\$7,270	2,690	2,690	\$8,090	Israel, >99%.
Inorganic bromine compounds:								
Ammonium, calcium, or zinc bromide	2827.59.2500	52,900	43,200	79,500	51,400	41,900	73,900	Israel, 96%.
Potassium bromate	2829.90.0500	52	25	317	37	18	146	India, 75%; Spain, 25%.
Potassium bromide ^{4,5}	2827.51.0000	761	511	1,310	695	467	1,200	China, 87%.
Sodium bromate	2829.90.2500	758	401 ^r	2,190	338	179	1,170	China, 100%.
Sodium bromide ^{4,5}	2827.51.0000	11,800	9,160	20,300	13,700	10,700	23,700	Israel, 86%; Belgium, 8%; China, 5%.
Organic bromine compounds:								
Decabromodiphenyl oxide and octabromodiphenyl oxide	2909.30.0700	846	676 ^r	4,220	445	356	2,400	China, 91%.
Dibromoneopentyl glycol	2905.59.3000	427	243 ^r	2,360	527	300	2,950	Israel, 66%; China, 34%.
Ethylene dibromide	2903.31.0000	22	19	167	--	--	--	
Hydrobromic acid	2811.19.3000	584	576 ^r	2,360	856	846	3,370	Israel, 92%.
Methyl bromide	2903.39.1520	109	92	731	146	123	857	Israel, 99%.
Tetrabromobisphenol A	2908.19.2500	1,040	610	3,480	884	519	3,920	China, 67%; Israel, 33%.
Total		71,900	58,000	124,000	71,800	58,100	122,000	

^rRevised. -- Zero.¹Table includes data available through June 29, 2017. Data are rounded to no more than three significant digits; may not add to totals shown.²Harmonized Tariff Schedule of the United States.³Import values are cost, insurance, and freight.⁴Source: PIERS.⁵Potassium bromide and sodium bromide import data are reported under a common HTS code.

Source: U.S. Census Bureau.

TABLE 5
SELECTED WORLD BROMINE ANNUAL PLANT CAPACITIES AND SOURCES AS OF DECEMBER 31, 2016¹

Country and company or plant	Location	Capacity (metric tons)	Source
China, Gulf Resources, Inc.	Shandong Province	47,300	Underground brines.
India:			
Hindustan Salts Ltd.	Kharaghoda	900	Seawater bitterns from salt production.
Solaris ChemTech Industries Ltd.	Khavda	NA	Do.
Tata Chemicals Ltd.	Mithapur	150	Do.
Israel, ICL Industrial Products	Sodom	280,000	Bitterns of potash production from surface brines.
Japan, Tosoh Corp.	Shunan	24,000	Seawater.
Jordan, Jordan Bromine Co. Ltd.	Safi	100,000	Bitterns of potash production from surface brines.
Turkmenistan:			
Cheleken Chemical Plant	Cheleken Region	NA	Seawater.
Nebitdag Iodine Plant	Vyshka	NA	Underground brines.
Ukraine, Perekop Bromine Plant	Krasnoperekopsk	NA	Do.

Do. ditto. NA Not available.

¹Table includes data available through June 29, 2017. Does not include U.S. production capacity.

TABLE 6
BROMINE: WORLD PRODUCTION, BY COUNTRY¹

(Metric tons)

Country ²	2012	2013	2014	2015	2016
China ^c	160,000 ^r	110,000	75,500 ^r	60,000 ^r	57,600
Germany ^c	1,600 ³	NA	NA	-- ^r	--
India ^c	1,700	1,700	1,700	1,700	1,700
Israel	173,940	172,341	173,796	115,583 ^r	162,000
Japan ^c	20,000	20,000	20,000	20,000	20,000
Jordan ^c	60,000 ^r	80,000	100,000	100,000	100,000
Turkmenistan ^c	480	500	500	500	500
Ukraine ^c	4,100	4,100	3,200 ^r	3,500	3,500
United States	W	W	W	W	W
Total ^{c,4}	422,000 ^r	389,000	375,000 ^r	301,000 ^r	345,000

^cEstimated. ^rRevised. NA Not available. W Withheld to avoid disclosing company proprietary data; not included in total. -- Zero.

¹Table includes data available through May 1, 2017. All data are reported unless otherwise noted. Totals and estimated data are rounded to three significant digits; may not add to totals shown.

²In addition to the countries listed, other nations, including Iran, may have produced bromine, but available information was inadequate to make reliable estimates of output.

³Includes bromides and oxides.

⁴Does not include U.S. production.