



# 2010 Minerals Yearbook

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## BROMINE

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# BROMINE

By Joyce A. Ober

**Domestic survey data and tables were prepared by Michelle B. Blackwell, statistical assistant, and the world production table was prepared by Lisa D. Miller, international data coordinator.**

The United States was the world's leading producer of bromine. The U.S. portion of world production has averaged about 44% during the past 30 years. World production of bromine for 2010, excluding the United States, was estimated to be 450,000 metric tons (t), compared with 378,000 t in 2009 (tables 1, 6). China, Israel, Jordan, the United States, and seven other countries produce bromine. In 2010, bromine sold or used in the United States increased significantly compared with that of 2009, but data were withheld to avoid disclosing company proprietary data.

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. Primary uses of bromine compounds were in flame retardants (FRs), drilling fluids, water treatment, and brominated pesticides (mostly methyl bromide).

## 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 (table 2). Albemarle Corp. and Chemtura Corp., both of which responded to the survey, represent 100% of total production. Production data collected by the USGS were withheld to avoid disclosing proprietary information (table 1). In January, Albemarle and Chemtura announced a strategic sourcing agreement. Chemtura agreed to purchase specific flame-retardant chemicals from Albemarle, and Albemarle assigned its brine interests at a brine unit in Union County, AR, to Chemtura, which is the operator of the unit (Chemtura Corp., 2010).

Bromine was recovered from brine wells in Arkansas, where brine is found in the Smackover Formation at a depth of about 2,400 meters with concentrations of 5,000 to 6,000 parts per million (ppm) bromine; by comparison, seawater contains 60 to 70 ppm bromine (Hill, 2010; Albemarle Corp., 2011, p. 55).

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).

## 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

from many organic reactions. This byproduct waste is recycled with virgin bromine brines and is a major source of bromine production. Plastics containing brominated FRs (BFRs) can be incinerated as a solid organic waste, and the bromine can be recovered (Frim and Ukeles, 2007).

## Consumption

The USGS did not collect consumption data on bromine compounds. Apparent consumption of bromine in the United States, calculated by the USGS from production plus imports minus exports, increased in 2009 owing to expanded demand resulting from improvements in the global economy. The major consumption categories, in order of magnitude, were FRs, drilling fluids, water treatment chemicals, and pesticides. Other uses included butyl rubber, dyes, mercury emission control, pharmaceuticals, photographic chemicals, and surfactants.

Estimated bromine consumption in BFRs was slightly less than 50%; BFRs are chemicals commonly used in many domestic and industrial appliances, electronic equipment, and other items, such as computers, furniture, insulation boards, mattresses, mobile telephones, televisions, and textiles. About 90% of all electrical components contain BFRs.

Late in 2009, Albemarle and Chemtura reached an agreement with the EPA for a voluntary phaseout of decabromodiphenyl ether (decaBDE) flame retardant. DecaBDE is used in consumer electronics, furniture, plastic shipping pallets, and textiles. The two companies signed a memorandum of understanding with the EPA to end production, importation, and sales of decaBDE for most uses by December 2012 and for all uses by the yearend 2013. Although not a producer of decaBDE in the United States, ICL Industrial Products (Tel Aviv, Israel) was a major importer of decaBDE into the United States and also agreed to the phaseout (U.S. Environmental Protection Agency, 2009). Albemarle developed a line of bromine-containing non-decaBDE flame retardants. Bromine was an important component in order to meet fire-safety standards for specific applications (Deligio, 2010).

Calcium bromide, sodium bromide, and zinc bromide, collectively referred to as clear brine fluids (CBFs), were 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, which is an alternative to using 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 compounds are effective pesticides, used both as soil fumigants in agriculture, particularly fruit growing, and as a fumigant to prevent pests from attacking stored grain and other produce. World trade in agricultural goods depends on the use of bromine compounds to ensure compliance with mandatory quarantine rules. Bromine compounds also are used as intermediates to make other agricultural chemicals. Methyl bromide is the leading bromine-containing pesticide in the world, but its use was declining owing to the ban imposed by the 1987 Montreal Protocol, which classified it as a class I ozone-depleting substance. As part of the Montreal Protocol, wealthy countries were to stop using the pesticide by 2005; however, the United States has received annual exemptions for crops and other critical uses (for example, cucumbers, melons, orchard replants, peppers, post-harvest uses, squash, strawberries, and tomatoes). The critical use exemption is for applications where no technically or economically feasible alternatives to methyl bromide exist. In 2010, the EPA authorized use of 2,984 t or 11.7% of the historic 1991 baseline consumption of methyl bromide for approved critical uses (U.S. Environmental Protection Agency, 2010, p. 23170). Use of methyl bromide also was allowed through a quarantine and preshipment exemption for agricultural commodities and lumber. Methyl bromide is a broad spectrum pesticide used in the control of nematodes, pathogens, pest insects, rodents, and weeds. Domestically, methyl bromide has proven to be difficult to replace because of its low cost and usefulness against a large variety of agricultural pests.

The use of bromine and bromine compounds to remove mercury from flue gas emissions at coal-fired electric powerplants was an expanding new use for bromine. Inorganic bromine compounds, such as calcium bromide and sodium bromide, when mixed with coal at powerplants, react with mercury in combustion zones, forming mercury compounds that are captured in scrubbers, removing 90% of mercury liberated during combustion (Chemtura Corp., 2009). Southern Research Institute (Birmingham, AL) developed a system that converts calcium bromide to elemental bromine gas, which then reacts with mercury to form mercuric bromide. The mercuric bromide is captured and retained in the powerplants' wet scrubbers (Southern Research Institute, 2010).

Albemarle and MeadWestvaco Corp. were partners in developing brominated wood-based activated carbons for use in mercury control (Albemarle Corp., 2009). Chemtura also offered bromine and brominated derivative products for use in the control of mercury emissions from coal-fired plants (Chemtura Corp., 2009).

## Transportation

Bromine in bulk quantities is transported in the United States in 7,570- and 15,140-liter (L) lead-lined pressure tank railcars or 6,435- to 6,813-L nickel-clad pressure tank trailers. The trailers must be filled at least 92% full to prevent inertia effects of the heavy liquid while on the highway. International shipments by The Dead Sea Bromine Group are in 15.2- to 23.3-t lead-lined tank containers (isotanks) with a volume of 5,300 to 8,000 L. For smaller quantities, lead lined tanks ("goslars") of 3.5 t (four tanks packed on one isoframe) and cylinders of 400 kilograms

are used. Dry nitrogen gas is recommended for use in pressure transferring bromine, 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

Because the bromine industry has few producers, published price lists of bromine and bromine compounds were not available. Although companies did not publish price data, they announced price changes without identifying the base price. For instance, Albemarle announced price increases of \$500 per metric ton of elemental bromine and \$250 per ton of hydrobromic acid twice during the year. By yearend, Albemarle prices for bromine and hydrobromic acid were \$1,000 and \$500 dollars per ton higher, respectively than at the beginning of 2010, but the actual price was not published. Albemarle and Chemtura made similar announcements throughout the year for other bromine compounds, indicating that prices for most bromine compounds rose during the year. A producer in China reported that elemental bromine reached almost \$2,800 per ton in China in August, up from about \$1,600 per ton at the beginning of 2010 (Watts, 2010). Prices in China do not necessarily correspond to prices in the United States but tended to corroborate other indications of price levels and trends.

Although not exactly the same as prices, average unit values of exported and imported bromine were used to identify price trends for bromine in 2010. The average value of exported elemental bromine, including cost, insurance, and freight, was \$1,760 per metric ton, a 13% increase from \$1,560 per ton in 2009. The average values of exported ethylene dibromide and methyl bromide increased 47% and 34%, respectively. The average value of imported elemental bromine increased by about 16% to \$2,510 per ton. Price trends for imported bromine compounds varied greatly. The compounds with the highest quantities of imports, however, including ammonium bromide, decaBDE, hydrobromic acid, sodium bromide, and tetrabromobisphenol A (all with more than 1,000 t of imports), all declined in average value, decreasing by 16% on average.

## Foreign Trade

Bromine exports were about 33% higher than those in 2009, although still 15% lower than those of 2008 (tables 1, 3). The value of exported elemental bromine and bromine compounds increased by 79% compared with that of 2009, reflecting the significant increase in prices for exported material. Bromine imports were about 25% lower than those of 2009, but total imports of bromine and bromine compounds were 28% higher. The import value of elemental bromine and most bromine compounds decreased, but the increased value of ammonium bromide, hydrobromic acid, potassium bromate, and sodium bromate were sufficient for total bromine imports to increase in value (tables 1, 4). Overall, the import value for elemental bromine and bromine compounds increased by 6% in 2010.

## World Review

The United States' share of world bromine production has decreased as other countries have strengthened their positions as world producers of elemental bromine. Israel, the United States, Jordan, China, Japan, and Turkmenistan, in descending order, had the leading bromine production capabilities in 2010, although none of these countries operated at capacity (table 5).

**European Union.**—In Europe, methyl bromine was banned in 2005 except for critical uses as part of the Montreal Protocol. As of March 18, 2010, all uses of methyl bromide were banned in the European Union without exception (Daily Mail, 2010).

**China.**—In China, bromine operations are in Shandong Province. Many unlicensed bromine facilities operated in the area, but since 2006, the Shandong Provincial government and the Government of China had closed down the unlicensed operations. Only six companies were licensed to produce bromine.

Gulf Resources, Inc. purchased several of the idled operations. Since 2007 through mid-2010, Gulf Resources acquired nine bromine operations, increasing its bromine production capacity to 46,300 metric tons per year (t/yr) from 12,000 t/yr. Gulf Resources planned to acquire 7 to 10 more bromine facilities. Although Gulf Resources represented only about 20% of China's bromine capacity, the company was perhaps the most well-known as a result of high-profile public relations activities in the United States (Nevader, 2010).

**Israel.**—ICL Industrial Products (Tel Aviv, Israel) was one of the world's leading producers of elemental bromine, with approximately 40% of global capacity. In 2010, ICL produced 185,000 t of elemental bromine. ICL processes brines from the Dead Sea, which contain 10 to 12 grams per liter (g/l) of bromine, much higher than the next richest source in U.S. brine wells that contain 2 to 6 g/l (ICL Industrial Products, undated).

## Outlook

Between 40% and 50% of domestic consumption of bromine is for FRs. In 2010, demand for FRs, particularly in the construction and electronics industries, increased as the economy recovered. Although FR usage fluctuates along with overall cycles in the economy, world consumption of FRs is expected to increase, assuming sustained economic growth. Recycling efforts in Europe for BFR plastics in electrical usage, which are easier to recycle than some other FR compounds, may increase the demand for BFR products. Use of BFRs, however, will likely increase at a slower pace than FRs in general because of legislative mandates and customer demand for more environmentally friendly materials.

The Freedonia Group forecast FR global consumption to rise by 4.7% per year through 2011 (Freedonia Group, The, 2007). The increase would be driven by the use of FRs in developing countries as they begin to adopt more stringent flammability standards and begin to use more plastic materials. Countries in Asia and the Pacific region would be the leading consumers of FRs, with consumption rising by 7% per year. More moderate growth in FR use was expected for markets in North America and Western Europe. U.S. consumption was forecast to rise by 2.7% per year through 2013 as a result of bromine use in

insulated wire and cable and in construction as well as more stringent fire codes and flammability requirements (Freedonia Group, The, 2009a). Above-average gains in the demand for FRs were expected to take place in Africa, Eastern Europe, the Middle East, and Latin America.

Bromine use in CBFs is highly dependent on fluctuations in the oil and natural gas drilling industry. Oil and gas drilling activity in the United States, measured by the number of wells drilled, was 12% higher in 2010 than in 2009, as a result of the economic recovery, but was still lower than in 2008 (American Petroleum Institute, 2011). Consumption of CBFs in crude oil and natural gas drilling was expected to increase as demand for these commodities increases.

Bromine water treatment chemical use was expected to show modest growth during the next several years. Bromine is used in both commercial and residential hot tubs, swimming pools, and whirlpools. In addition, bromine is used to treat industrial cooling water. Bromine has been found to be safer than its substitutes in sanitary preparations because bromine has a higher biocidal activity level for the same volume of product. The use of bromine compounds was expected to continue increasing in the hot tub, spa, and swimming pool sector as a gentler disinfectant than chlorine. Global demand for water treatment products was projected to increase in developing markets, such as China and India, as a result of continued industrial expansion and increased efforts to expand access to safe water supplies (Freedonia Group, The, 2009b).

Bromine use in photography is declining as digital imaging replaces film in consumer and professional photography. Most feature films for movie theater presentation are shot using printed film; however, the use of digital technology was expected to increase and overtake film in these applications during the next decade.

The market potential for bromide-based technologies to remove mercury emissions at coal-fired powerplants is an area of potential growth for the industry. Using bromide compounds to neutralize mercury emissions appears to be more cost effective compared with other materials like chlorine-, fluorine-, or iodine-base compounds. New regulations proposed by the EPA in early 2011 for reducing mercury emissions at powerplants by an estimated 91% were likely to increase demand for bromine and bromine compounds for that application (U.S. Environmental Protection Agency, 2011).

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TABLE 1  
 SALIENT BROMINE STATISTICS<sup>1</sup>

(Metric tons and thousand dollars)

	2006	2007	2008	2009	2010
<b>United States:</b>					
<b>Bromine sold or used:<sup>2</sup></b>					
Quantity	243,000	W	W	W	W
Value	339,000	W	W	W	W
<b>Exports:<sup>3</sup></b>					
Quantity	12,400	8,560	9,640	6,120	8,150
Value	23,000	15,200	16,200	12,400	22,300
<b>Imports for consumption:<sup>4</sup></b>					
Quantity	43,100	32,200	41,200	35,000 <sup>r</sup>	45,000
Value	78,100	817,000	97,300	83,300	88,000
Apparent consumption	275,000	W	W	W	W
World, production <sup>e</sup>	671,000 <sup>r</sup>	415,000 <sup>r,6</sup>	415,000 <sup>r,6</sup>	378,000 <sup>r,6</sup>	450,000 <sup>6</sup>

<sup>e</sup>Estimated. <sup>r</sup>Revised. W Withheld to avoid disclosing company proprietary data.

<sup>1</sup>Data are rounded to no more than three significant digits.

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

<sup>3</sup>Export values are free alongside ship.

<sup>4</sup>Source: U.S. Census Bureau or PIERS (see table 4).

<sup>5</sup>Import values are cost, insurance, and freight.

<sup>6</sup>Excludes U.S. production.

TABLE 2  
ELEMENTAL-BROMINE-PRODUCING PLANTS IN THE UNITED STATES IN 2010

State and company	County	Plant	Production source	Capacity <sup>1</sup> (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 <sup>2</sup>
Chemtura Corp.	do.	El Dorado Central and El Dorado South	do.	71 <sup>3</sup>
Do.	do.	Marysville West	do.	36
Do.	do.	Newell	do.	23
Total				59
Grand total				278

Do., do. Ditto. NA Not available.

<sup>1</sup>Actual production capacity is limited by brine availability.

<sup>2</sup>Cumulative capacity of Magnolia South, Magnolia West, and Satellite plants.

<sup>3</sup>Cumulative capacity of El Dorado Central and El Dorado South plants.

TABLE 3  
U.S. EXPORTS OF BROMINE AND BROMINE COMPOUNDS<sup>1,2</sup>

Compound	HTS <sup>3</sup> number	2009			2010		
		(metric tons)		Value <sup>4</sup>	(metric tons)		Value <sup>4</sup>
		Gross weight	Br equivalent	(thousands)	Gross weight	Br equivalent	(thousands)
Elemental bromine	2801.30.2000	3,810	3,810	\$5,930	4,530	4,530	\$7,970
Other compounds:							
Ethylene dibromide	2903.31.0000	1,760	1,500	4,320	2,270	1,930	8,180
Methyl bromide	2903.39.1520	968	815	2,190	2,000	1,690	6,090
Grand total		6,540	6,120	12,400	8,810	8,150	22,300

<sup>1</sup>These data detail the information included in table 1 under "Exports."

<sup>2</sup>Data are rounded to no more than three significant digits; may not add to totals shown.

<sup>3</sup>Harmonized Tariff Schedule of the United States.

<sup>4</sup>Declared cost, insurance, and freight valuation.

Source: U.S. Census Bureau.

TABLE 4  
U.S. IMPORTS OF BROMINE AND BROMINE COMPOUNDS<sup>1,2</sup>

Compound	HTS <sup>3</sup> number	2009				2010			
		(metric tons)		Value <sup>4</sup> (thousands)	(metric tons)		Value <sup>4</sup> (thousands)	Principal sources in 2010	
		Gross weight	Br equivalent		Gross weight	Br equivalent			
Elemental bromine	2801.30.2000	1,390	1,390	\$3,020	1,040	1,040	\$2,620	Israel, 54%; Jordan, 42%.	
Inorganic bromine compounds:									
Ammonium bromide	2827.59.2500	25,600	20,900	39,200	38,600	31,500	50,400	Israel, 93%.	
Calcium bromide <sup>5</sup>	2827.59.2500	1,760	1,410	1,690 <sup>e</sup>	255	204	403 <sup>e</sup>	China, 100%.	
Potassium bromate	2829.90.0500	54	26	203	53	25	244	China, 100%.	
Potassium bromide <sup>5,6</sup>	2827.51.0000	279	187	1,170 <sup>e</sup>	121	81	249 <sup>e</sup>	France, 53%; Israel, 31%; China, 16%.	
Sodium bromate	2829.90.2500	223	118	547	575	305	1,770	China, 100%.	
Sodium bromide <sup>5,6</sup>	2827.51.0000	6,490	5,040	11,900 <sup>e</sup>	8,030	6,230	11,700 <sup>e</sup>	Israel, 70%; China, 19%.	
Organic bromine compounds:									
Hydrobromic acid	2811.19.3000	970	958	1,520	1,540	1,520	1,750	Israel, 65%; France, 18%.	
Ethylene dibromide	2903.31.0000	105	89	178	21	18	117	China, 95%.	
Methyl bromide	2903.39.1520	565	476	4,260	367	309	2,350	Israel, 73%; China, 20%.	
Dibromoneopentyl glycol <sup>5</sup>	2905.50.3000	606	345	NA	130	74	618 <sup>e</sup>	Israel, 85%; China, 15%.	
Tetrabromobisphenol A	2908.19.2500	1,860	1,090 <sup>f</sup>	7,250	1,310	768	4,410	Israel, 93%.	
Decabromodiphenyl oxide and octabromodiphenyl oxide	2909.30.0700	3,810	3,050 <sup>f</sup>	12,400	3,610	2,890	11,500	Israel, 90%; China, 10%.	
Grand total		43,700	35,000 <sup>f</sup>	83,300	55,700	45,000	88,000		

<sup>e</sup>Estimated. Revised. NA Not available.

<sup>f</sup>These data detail the information included in table 1 under "Imports for consumption."

<sup>2</sup>Data are rounded to no more than three significant digits; may not add to totals shown.

<sup>3</sup>Harmonized Tariff Schedule of the United States.

<sup>4</sup>Declared cost, insurance, and freight valuation.

<sup>5</sup>Source: PIERS.

<sup>6</sup>Potassium bromide and sodium bromide import data are reported under a common HTS number, 2827.51.0000.

Source: U.S. Census Bureau.

TABLE 5  
WORLD BROMINE ANNUAL PLANT CAPACITIES AND SOURCES AS OF DECEMBER 31, 2010<sup>1</sup>

Country and company or plant	Location	Capacity (metric tons)	Source
Azerbaijan, Neftechala Bromine Plant	Baku	4,000	Underground brines.
China, Laizhou Bromine Works	Shandong	43,000	Do.
India:			
Hindustan Salts Ltd.	Jaipur	NA	Seawater bitterns from salt production.
Mettur Chemicals Ltd.	Mettur Dam	NA	Do.
Tata Chemicals Ltd.	Mithapur	NA	Do.
Total		1,500	
Israel, ICL Industrial Products	Sdom	280,000	Bitterns of potash production from surface brines.
Japan, Toyo Soda Manufacturing Co. Ltd.	Tokuyama	20,000	Seawater.
Jordan, Jordan Bromine Co. Ltd.	Safi	50,000	Bitterns of potash production from surface brines.
Spain, Derivados del Etilo S.A.	Villaricos	900	Seawater.
Turkmenistan:			
Cheleken Chemical Plant	Cheleken Region	4,740	Do.
Nebitdag Iodine Plant	Vyshka	2,370	Underground brines.
Ukraine, Perekop Bromine Plant	Krasnoperekopsk	3,000	Do.

Do. ditto. NA Not available.

<sup>1</sup>Excludes U.S. production capacity, which is detailed in table 2.

TABLE 6  
BROMINE: ESTIMATED WORLD REFINERY PRODUCTION, BY COUNTRY<sup>1,2</sup>

(Metric tons)

Country <sup>3</sup>	2006	2007	2008	2009	2010
Azerbaijan	2,000	2,000	3,500	3,500	3,500
China	124,000	137,000	135,000	140,000	150,000
Germany <sup>4</sup>	431 <sup>5</sup>	1,612 <sup>5</sup>	840 <sup>r</sup>	507 <sup>r</sup>	985
India	1,500	1,500	1,500	1,500	1,500
Israel	179,493 <sup>5</sup>	159,395 <sup>5</sup>	164,042 <sup>5</sup>	127,689 <sup>r,5</sup>	185,000 <sup>5</sup>
Japan	20,000	20,000	20,000	20,000	20,000
Jordan	94,500 <sup>5</sup>	85,105 <sup>5</sup>	85,000	80,000	85,000
Spain	100	100	100	100	100
Turkmenistan	150	150	150	150	150
Ukraine	5,150 <sup>r</sup>	7,824 <sup>r,5</sup>	4,416 <sup>r,5</sup>	4,121 <sup>r,5</sup>	4,100
United States <sup>6</sup>	243,000 <sup>5</sup>	W	W	W	W
Total	671,000 <sup>r</sup>	415,000 <sup>r,7</sup>	415,000 <sup>r,7</sup>	378,000 <sup>r,7</sup>	450,000 <sup>7</sup>

<sup>r</sup>Revised. W Withheld to avoid disclosing company proprietary data; not included in total.

<sup>1</sup>World totals, U.S. data, and estimated data are rounded to no more than three significant digits; may not add to totals shown.

<sup>2</sup>Table includes data available through May 11, 2011.

<sup>3</sup>In addition to the countries listed, several other nations, including Iran, produced bromine, but output data were not reported; available general information is inadequate to formulate reliable estimates of output levels.

<sup>4</sup>Includes bromides and oxides.

<sup>5</sup>Reported figure.

<sup>6</sup>Sold or used by producers.

<sup>7</sup>Excludes U.S. production.