

BROMINE

By Phyllis A. Lyday

Domestic survey data and tables were prepared by Maria Arguelles, statistical assistant, and the world production table was prepared by Glenn J. Wallace, international data coordinator.

Bromine is a natural element widely found in nature, principally in seawater, salt lakes, and underground brines associated with oil. The quantity of bromine sold or used in the United States was 228 million kilograms (Mkg) valued at \$206 million (table 1). The value of bromine sold or used was \$0.90 per kilogram (table 3). Primary uses of bromine compounds were in flame retardants (40%), drilling fluids (24%), brominated pesticides (mostly methyl bromide) (12%), water-treatment chemicals (7%), and others, including photographic chemicals and rubber additives (17%) (Chemical Market Reporter, 1999a). International distribution of bromine production for 2000 was estimated to be as follows: the United States, 45%; Israel, 35%; China, 9%; the United Kingdom, 5%; and other countries, 6% (table 6). Because of depleting reserves, distribution and economics, environmental constraints, and the emergence of Israel as the world's second largest producer with 36% of the world market, the U.S. portion of world production decreased steadily since 1973, when the United States produced 71% of the world supply, to 42% in 2000.

Legislation and Government Programs

Methyl bromide was listed as a class I ozone-depleting substance in the 1990 Clean Air Act (CAA) and was scheduled to be phased out in the United States by January 1, 2001. The U.S. Congress extended the phase out of methyl bromide until January 1, 2005, to coincide with the deadline for developed countries under the Montreal Protocol on Substances that

Deplete the Ozone Layer. Under the Clean Air Act Amendments of 1990 (Public Law 101-549), U.S. production and imports of bromine must be reduced from 1991 levels as follows: 25% by 1999; 50% by 2001; 70% by 2003; and a full ban by 2005. Domestically, methyl bromide had proven to be a difficult pesticide to replace because of its low cost and usefulness against a large variety of agricultural pests. The amendment allowed for the exemption of critical uses of methyl bromide that have not been yet defined. The dominant use was for preplanting soil treatments. It also was used for structural applications, such as termite treatments. The United States consumed methyl bromide as a preplant fumigant for tomatoes (30%), strawberries (19%), and peppers, (14%). About 50% was consumed in California and 30% in Florida. (Hess, 2000). Three producers, Albemarle Corp., Great Lakes Chemical Corp., and Israel's Dead Sea Bromine Co. Ltd. (DSB), were the major manufacturers. Under the Montreal Protocol, developing countries had until 2015 to phase out methyl bromide production.

A report by environmental groups that predicted a national assessment of how global warming might affect the U.S. climate over the next 100 years was criticized by the Competitive Enterprise Institute as "a scientifically dishonest, alarmist document based on junk science." Critics stated the report sought to advance "a political agenda rather than look at the state of the science and its uncertainties involving the theory of climate change." Other deficiencies were predictions about future weather conditions that were "simply not scientifically possible with current technology" (Chemical

Bromine in the 20th Century

In 1901, production of bromine from brines associated with salt production was reported by the U.S. Geological Survey from Michigan, Ohio, Pennsylvania, and West Virginia to be 245,867 kilograms (542,043 pounds) valued at \$154,472. The consumption was primarily for use in medicine, photography, and analytical and experimental chemistry. As bromine became more readily available, uses increased and included dissolving gold and separating it from platinum and silver, acting as an oxidizer, and uses in disinfectants, salts, and aniline dyes. During World War I, bromine was used extensively in asphyxiating gases in Europe. By 1918, bromine production had increased in quantity to 783,426 kilograms (1,727,156 pounds) valued at \$970,099. In 1921, tetraethyl lead was used to reduce knock or pinging in internal-combustion engines. Bromine sold by producers in 1924 increased to 922,519 kilograms (2,033,804 pounds) valued at \$594,685 as a result of use in the manufacture of ethylene dibromide used as a scavenger for tetraethyl lead. In

1924, E.I. du Pont de Nemours & Co. Inc. conducted successful experiments to produce bromides from seawater on a specially equipped ship named U.S. *Ethyl*. Dow Chemical Co. found bromine-rich brines in Midland, MI, and began production in 1925. By 1930, over 1,350 metric tons (3 million pounds) of bromine was produced. Bromine production began in Arkansas in 1965, and Arkansas quickly became the world's leading bromine producer. Ethylene dibromide continued to be the major use for bromine until lead was banned in gasoline in 1976 and was phased out by 1978.

In 2000, U.S. production of 228 tons valued at \$206 million came from brines in Arkansas and Michigan. Bromine markets included the oil- and gas-well drilling industry, automobile tires, soil and grain fumigation, photographic papers and chemicals, gold ore processing chemicals, fire retardants for plastics, and biocides in indoor hot tubs, swimming pools, and recirculatory cooling systems.

Market Reporter, 2000e).

The U.S. Environmental Protection Agency (EPA) announced a new office for information management, information policy, and technology stewardship that would be headed by a national program manager. The new office included the highly visible Toxics Release Program, which had been run in the past in the Office of Pollution Prevention and Toxics. The data collection and analysis functions that had been scattered throughout the agency would be consolidated to include environmental statistics, one-stop reporting, single-facility identification, and watershed information (U.S. Environmental Protection Agency, [undated], Pesticides, toxics and chemical projects and programs, accessed April 25, 2000, at URL <http://www.epa.gov/epahome/pestoxpgram.htm>).

Bromine was taxed under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (Superfund) (Public Law 96-510) that had gone through two reauthorizations since its enactment in 1980. The 1986 Superfund Amendments and Reauthorization Act (Public Law 99-499) made considerable changes to the remedy selection component of the law. A second reauthorization in 1990 extended only the program and its taxing authority. Superfund taxes on industry, which generated \$1.6 billion per year, had not been collected since December 1995. The Superfund Trust Fund was projected to run out of money in 2000. By yearend, the Superfund had not been amended.

The EPA, the Environmental Defense Fund, and the American Chemistry Council announced that 192 of the Nation's largest chemical and oil companies, including 2 that produce bromine, had volunteered to ensure that approximately 1,100 commonly used chemicals were screened for basic toxicity; the companies were Chemical Manufacturers Association (CMA) members (Johnson, 1999). The agreement was a significant step toward gathering complete screening data for 2,800 high production volume chemicals that were used or imported in quantities exceeding 454 metric tons per year (t/yr) (1 million pounds per year). CMA's Internet tracking publicly displayed the chemicals and timetables set for the companies (Chemical Manufacturers Association, [undated], HPV challenge website, accessed April 25, 2000, at URL <http://www.cmahq.com>). The Council of Chemical Associations, an international industry trade association, set a goal of testing 1,000 chemicals by 2004. The toxicity testing would be carried out under a cost-sharing program operated by the Organization of Economic Cooperation and Development, which comprised 29 countries, including the United States. The Synthetic Organic Chemical Manufacturers Association announced its support of the program as a result of commitments made by the EPA.

The EPA published in the Federal Register of December 7, 1999, its final rule for the revisions to the underground injection control regulations for class V injection wells. A study was conducted to develop background information used to evaluate the risk of these wells to underground sources of drinking water and to determine whether additional Federal regulation was warranted. Bromine was included in volume 9, "Spent Brine Return Flow Wells." In Arkansas, all 74 of the class V spent brine return wells were associated with facilities that produced bromide compounds from brine extracted from the Smackover Formation 6,000 feet below the lowermost underground source of drinking water (USDW). The chemical characteristics of the injected spent brine were determined primarily by the

characteristics of the brine that was withdrawn for processing. In Arkansas, available data indicated that concentrations of barium and boron in spent brine routinely exceed primary maximum contaminant levels or health advisory levels. Arkansas was an underground injection code (UIC) primacy state for class V wells, so the Arkansas Oil and Gas Commission had jurisdiction over permitting, construction, and operation requirements. In Michigan, 24 spent brine wells were associated with production of magnesium, bromide, and calcium compounds from the Filer Sandstone Formation 2,000 feet beneath the lowermost USDW. In Michigan, EPA region 5 implemented the UIC class V program. In addition, the Geological Survey Division of the Michigan Department of Environmental Quality had authority to establish standards for construction, testing, operations, and plugging and abandonment of mineral wells and to permit such wells (U.S. Environmental Protection Agency, September 30, 1999, The class V underground injection control study—Volume 9—Spent brine return flow wells, accessed April 18, 2001, at URL <http://www.epa.gov/safewater/uic/classv/volume9.pdf>).

The U.S. Department of Transportation published a notice of final rulemaking for the Research and Special Programs Administration amending certain requirements in the hazardous materials regulations to enhance safety and to align with international standards. Changes to the hazardous materials table included removing 1-chloro-3-bromopropane and adding 1-bromo-3-chloropropane (U.S. Department of Transportation, 2000).

The Consumer Product Safety Commission held public hearings in 1998 to receive scientific and technical information relating to the toxicity, exposure, bioavailability, and environmental effects of flame retardant chemicals, including bromine compounds, that may be suitable for use in residential upholstered furniture. The Commission would evaluate the information obtained from the hearings as part of its deliberations on whether to propose a standard to address the hazard associated with small open-flame ignitions of upholstered furniture. At yearend 1999, the study was still in the information-gathering stage. In 2000, the study was in the draft stage.

The U.S. Department of Justice (DOJ) and the European Commission had been investigating the bromine industry for possible violations of antitrust laws. DSB pleaded guilty and paid a \$7 million criminal fine for participating in a price-fixing conspiracy to eliminate competition in connection with the sale of certain flame-retardant products [tetrabromobisphenol-A (TBBA) and decabromodiphenyloxide] and the fumigant methyl bromide in the United States. Great Lakes had been granted U.S. amnesty from criminal prosecution in the investigation. DSB was charged with fixing prices in the United States between July 1995 and April 1998. The continuing investigation was being conducted in the DOJ Antitrust Division's field office in Dallas and the Federal Bureau of Investigation (Chemical Market Reporter, 2000g; Industrial Minerals, 2000e).

The EPA asked the chemical manufacturers to voluntarily test 23 substances, including ethylene dibromide, to which children were exposed in everyday life. The EPA would use data generated in the first round of its Voluntary Children's Chemical Evaluation Program to examine the risk from chemicals found in the human body that come from food,

water, or air. The agency planned to evaluate and revise the program after the first tests and to expand it to include more chemicals (Hogue, 2001).

Production

Domestic production data for bromine were developed by the U.S. Geological Survey from a voluntary survey of U.S. operations. Of the operations to which a survey request was sent, six responded, representing 100% of total elemental bromine produced (table 1).

Albemarle's bromine production included three plant sites in south Arkansas with the addition of their new satellite facility in Union County, which was started up in July 2000. Albemarle had 31 bromine production wells, 6 of which also produced oil. Brine wells were twice as wide and twice as deep as typical Arkansas oil wells, and the brine that was produced exceeded 110° C (230° F). Albemarle owned 17.4% of the production from the west unit operated by Great Lakes in Union County and, as a result, produced bromine at their satellite plant from five additional wells in the unit.

Albemarle reported that the 50,000-t/yr TBBA plant was operational in Magnolia, AR. An improved TBBA, marketed under the trade name SAYTEX CP-2000, was widely used in many plastics systems. CP-2000 was used in reactive monomer in polycarbonates and epoxy polymers and was a major reactive component in epoxy oligomers used as an additive (nonreacting) flame retardant in acrylonitrile-butadiene-styrene systems. Albemarle began producing CP-2000 in late 1999 by use of a patented continuous reacting process. This distinguished CP-2000 from all other competitive offerings of TBBA that were produced by a batch reaction process.

Bromine flame retardants were used in electronic equipment to increase the fire resistance of the plastic housings and the computer printed circuit boards. TBBA also was used in carpets, computer housings and electrical connectors, and office furniture (Warren, 2000). These applications included communications, construction, electronics, textiles application, and transportation (42%). According to Albemarle, other bromine derivatives end uses were: pharmaceuticals, photography, rubber, and water treatment (30%); gasoline additives and oilfield completion fluids (20%); and agricultural chemicals and fumigants (15%) (Chemical Market Reporter, 1999b). Albemarle received EPA approval for Stabrom™ 909 biocide (Chemical Market Reporter, 2000a). Albemarle expanded sales of brominated biocides to the 50 States and Europe. Albemarle also operated two bromine derivatives plants in France.

Albemarle and Borax Polymer Additives Group signed an agreement that allowed Albemarle to offer zinc borate flame- and smoke-suppressing products in Asia. Zinc borate can replace antimony oxide as a synergist and can be combined with other mineral-based additives to be used as a synergist with SAYTEX flame retardants (Chemical Market Reporter, 2000a).

Albemarle purchased Ferro Corp.'s Pyro-Chek® flame-retardants business along with a plant at Port-de-Bouc, France. Ferro retained ownership of its Hammond, IN, facility, but stopped manufacturing brominated polystyrene flame retardants at that site (Chemical Market Reporter, 2000b).

Great Lakes Chemical continued production of bromine from brines at four plants in Arkansas. The company also owned

Associated Octel Co. Ltd. of the United Kingdom. Great Lakes reached an agreement to acquire Aqua Clear Industries LLC. Aqua Clear's products and retail markets were complementary to those of the Great Lakes subsidiary Bio-Lab, Inc. (Chemical Market Reporter, 2000h). Bio-Lab received regulatory clearance from the U.S. Food and Drug Administration for the use of BromiCide® in the manufacture of food-contact paper and paperboard.

TETRA Technologies, Inc. was one of the largest users of brominated products in the world. Calcium, sodium, and zinc bromide, collectively referred to as clear brine fluids (CBFs), were used in oil and gas applications. CBFs have high specific gravities and were used in completion and workover activities to reduce the likelihood of damage to the well bore and productive pay zone. Calcium bromide and zinc bromide were purchased from two domestic and one foreign manufacturer, and TETRA recycled calcium and zinc bromide CBFs repurchased from its oil and gas customers. The West Memphis, AR, facility produced calcium bromide and zinc bromide using zinc-containing sludge from electroplating operations and low-cost hydrobromic acid. TETRA began operation of merchant bromine, calcium bromide, and sodium bromide plant at the Dow Chemical Co. Ludington, MI, facility in mid-1998 using purchased crude bromine from Dow's calcium-magnesium chemicals operation. The liquid sodium bromide was sold to the industrial water treatment markets. TETRA also owned a plant in Magnolia, AR, that was designed to produce calcium bromide but was not operational in 2000. Approximately 13,400 hectares (33,000 gross acres) of bromine containing brine reserves in the vicinity of the plant were under lease (TETRA Technologies, Inc., 2000).

Consumption

Global estimates of world market share of brominated flame retardants (BFR) listed Great Lakes Chemical with 31%; Albemarle with 23%; DSB with 22%; and others with 24%. The demand for BFR was expected to reach 680 Mkg (1.5 billion pounds) by 2003, according to Cleveland-based Freedonia Group. Merrill Lynch estimated sales from BFR to be \$210 million for Albemarle. Salomon Smith Barney estimated that Great Lakes sales were \$271.7 million (Lerner, 2000). It was estimated that the world market for flame retardants for plastics stood at approximately \$2.2 billion and would grow at 5% to 6% per year through 2003 (Chemical Business Newsbase, 1999c).

There were many different flame retardants that included bromine, chlorine, phosphorus, nitrogen, and other elements. Flame retardants are chemicals that suppress the combustion process. They prevent the spread of fires or delay the time of flashover so that people have additional time to escape. It is estimated that BFRs accounted for 39% of the worldwide market in 1998. Consumption by final application was reported as follows: electronics and electrical, 56%; building and construction, 31%; textile, 7%; and transformers, 6%. The distribution of BFR use in electrical and electronic components use was reported as follows: household appliances, 59%; printed wiring boards, 30%; connectors and relays, 9%; and wire and cabling, 2%. In 1999, consumption by region was as follows: Asia, 56.2%; the Americas, 28.7%; and Europe 15.1% (Bromine Science and Environmental Forum, 2000, An

introduction to brominated flame retardants, accessed April 15, 2000, at URL <http://www.bsef.com>).

Albemarle's fine chemicals division also included surface actives, bromine, and oilfield chemicals. The company had manufacturing units in Feluy, Belgium; Port-de-Bouc, Thann, France; and Teesport, United Kingdom. The Teesport facility functioned as a custom manufacturing and oilfield chemicals plant.

The EPA's methyl bromide phaseout program stated that those applications still using methyl bromide by 2005 would do so because they had no choice. Methyl bromide was still the common chemical used to limit the spread of damaging insect populations around the world. The U.S. Department of Agriculture recommended the use of methyl bromide to treat wood packaging materials from China because of the lack of good alternatives. A voracious, nonnative insect pest had been found in material at 26 scattered warehouse and residential sites in 14 States. China could end up having to use more than 12,500 metric tons (t) of methyl bromide to treat wood destined for the United States. This would represent a 75% increase in use in Asia compared with 1996 levels for all applications, including soil treatment. The EPA figures showed that only 4,070 t, or about 6% of all methyl bromide used globally, was used to fumigate timber worldwide in 1996 (Reisch, 1998).

Pesticides, such as bromine compounds, were used to protect food from pests, such as bacteria, insects, mold, rodents, and weeds. In 1996, Congress passed the Food Quality Protection Act (FQPA) to improve the safety of food and to protect the public from exposure to pesticides. With the passage of this act, the jurisdiction of food-contact antimicrobials shifted from the Food and Drug Administration to the EPA. The EPA asserted that conclusions concerning the dangers of pesticides in food were not credible and were unnecessarily alarmist (Chemical Market Reporter, 1999c). The EPA set standards on the amount of pesticides that may remain on food if pesticides were applied. The FQPA set a tougher standard for pesticide use on food. By 2006, the EPA was required to review all old pesticides safety standards to make sure that their use on food met the new safety standard. If a pesticide was authorized that did not meet the safety standard, then the EPA would work with grocery stores to inform consumers of such pesticides and foods that might contain them.

World Review

Publication of the International Organization for Standardization (ISO) 9000 standards was planned for November 2000. Bromine operations were part of the 200,000 ISO-9000-based quality-management systems being operated worldwide to ensure internal efficiency and customer specified requirements for the product (International Organization for Standardization, [undated], ISO revisions, accessed July 2, 1999, at URL <http://www.bsi.org.uk/bsi/services/isorevs.htm>; International Organization for Standardization, [undated], Welcome, accessed July 2, 1999, at URL <http://www.iso.ch>).

Azerbaijan.—The Neftchala iodine-bromine plant produced 4,000 t/yr of bromine from waters from oil wells in the Neftchala and Khillinsky oilfields, Prikurinsky Basin. The bromine reserves were estimated to be 100,000 t. To modernize and commission the plant, an investment of \$1.4 million was required (Industrial Minerals, 2000c).

China.—Ocean Chemicals Group, Asia's largest elemental bromine producer, opened its first European sales agency in Old Glossop, United Kingdom. The agency planned to market bromine and bromine derivatives produced in China. The group produced 75,000 t/yr of bromine and bromine derivatives with sales estimated to be \$1.2 billion per year (Chemical Business Newsbase, 1999b).

Construction began on the first phase of a bromide manufacturing joint venture in Weifang, Shandong Province. The venture was split between the Dead Sea Bromine Group and Haiha Group of Weifang. The new plant would produce a range of high-technology products of which the company planned to export 60% (Industrial Minerals, 2000b).

Denmark.—The Danish Environmental Protection Agency had drawn up a plan to progressively limit and stop the use of BFRs. A major part of BFR consumption was in imported goods, such as cars, computers, and television sets. The plan contained a large number of initiatives, such as build-up knowledge, information to consumers, international regulation and cooperation, national agreements, standardization, and subsidies for the development of alternatives to BFRs (Ministry of Environment and Energy, 2000, Danish Environmental & Energy Newsletter—Brominated flame retardants—Denmark is to limit the use of brominated fire retardants, accessed September 14, 2000, at URL <http://www.mex.dk/uk/bromin.asp>).

European Union.—The European Commission created three separate pieces of legislation out of the original draft directive on waste electrical and electronic equipment, which served to intensify the focus on BFRs. Under the draft, substitution of other flame retardants for polybrominated biphenyls (PBB) and polybrominated diphenylethers (PBDE) in electrical and electronic equipment was required to be completed by January 1, 2008. Restrictions on the BFRs would ban some of the most effective flame retardants available at a time in which politicians and firefighters were requesting increased levels of flame retardants for plastics in certain electrical and electronics applications. The ban on PBB would not affect the plastics market; PBDE, however, was still a widely used flame retardant in electrical plastics. The Commission was concerned about landfilling, incinerating, and recycling plastics containing BFRs because the end product could contain brominated dibenzofurans and brominated dibenzo-p-dioxins, which may be toxic. Separating out all plastics containing BFRs would present an additional cost to waste management because some of the plastics were fully recyclable and others, which contained brominated epoxy oligomer, had distinct advantages in terms of recyclability (Mapleston, 2000).

France.—Elf Atochem SA continued to switch from producing bromide derivatives to fine chemicals at its Port-de-Bouc plant in southeast France. The complex included a 12,000-t/yr bromine plant that supplied the downstream units. The company invested \$12.8 million in the plant to produce alkyl bromides and dibromide, as well as ultrapure hydrobromic acid. Autofina completed a new 1,200-t/yr bromo-acids and bromo-esters plant. Albemarle operated a bromine derivatives facility at Thann and a flame retardants plant at Port-de-Bouc. Most of the production of brominated intermediates was sold to the pharmaceutical industry (Industrial Minerals, 2000d).

India.—Tamil Nadu Salt Corp. Ltd. planned a bromine plant

at the Valinokkam complex. The bromine would be a byproduct of salt production (Businessline, 1999, India—Tamil Nadu Salt Corp. to expand Valinokkam plant, accessed April 28, 2000, at URL <http://www.proquest.umi.com>).

Israel.—The production of bromine and potash began in 1931 at Kalia. The soluble minerals existed mainly as bromine and chloride anions and magnesium, potassium, and sodium cations. Bromine had been produced as a byproduct from waste bitterns associated with potash production from the Dead Sea since 1957 by DSB. After potash was removed in solar ponds, the waste bitterns were processed with chlorine to recover bromine. The brine contained 14,000 parts per million of bromine. The bromine-free bitterns were then processed to recover magnesium (Chemical Business Newsbase, 1999a).

In 1985, the Israeli Government began efforts to sell a share of Israeli Chemical Co. Ltd. (ICL) to offset an investment program. ICL was a group of chemical and mineral industrial companies, with commercial and marketing services, research institutes, and technical facilities. Israel Corp. bought an additional 17% stake in March 1997, which brought its total share of ICL to 41.9%. In 1997, the Israeli Government announced its decision to sell off its 31.5% stake of ICL valued at \$441 million; the sale required the approval of the finance committee of the Israeli Parliament. In 1999, Potash Corp. of Saskatchewan planned to purchase as much as 30% of ICL.

DSB was a major producer of bromine and bromine compounds. The company was 89% owned by ICL. DSB, in turn, owned a number of subsidiaries. ICL made an offer to purchase the remaining 11% of DSB for \$60 million (Chemical Market Reporter, 2000f). DSB had bromine manufacturing facilities at the Sdom plant and organic and inorganic bromine compounds at Ramat Hovav, and Broomchemie BV operated its subsidiary in the Netherlands (Chemical Business Newsbase, 1999d).

Japan.—Tosoh Corp. was Japan's only producer of bromine and hydrobromic acid used in the manufacture of dyes, flame retardants, pharmaceuticals, and photosensitive materials (Tosoh Corp., [undated], Bromines & flame retardants, accessed January 7, 2000, at URL <http://www.tosoh.com/EnglishHomePage/tcdiv/tcdinbro.htm>).

Jordan.—Jordan Bromine Co. Ltd., a joint venture between Arab Potash Co. (APC), its subsidiary Jordan Dead Sea Industries Co. (JODICO), and Albemarle Holdings Co. Ltd. of the United States, was incorporated in Jordan on January 11, 1999. APC had since purchased JODICO's shares in the joint venture resulting in a 50-50 joint venture between APC and Albemarle Holdings. A \$150 million bromine complex in Safi included a 50,000-t/yr bromine plant, a 40,000-t/yr calcium bromide plant, and a 12,500-t/yr initial capacity TBBPA plant expandable to 37,500-t/yr. The plant would produce bromine for the merchant market and derivatives facilities, including inorganic bromides for oilfield completion fluids and TBBPA as a flame retardant, primarily for marketing in Europe and Asia (Kendall, 2000). Agra Monenco Inc. of Canada was awarded a contract to perform engineering, procurement, and construction management (Industrial Minerals, 2000a). Jordan Bromine obtained a loan from the European Investment Bank for the project.

Ukraine.—JSC Brom of Krasnoperekopsk, located at the Sivash Gulf on the Sea of Azov in Crimea, was reported to have 52,000 t/yr of bromine capacity (Industrial Minerals, 1998).

United Kingdom.—Production of bromine increased during 1999. Albemarle UK Ltd., a subsidiary of Albemarle, announced the acquisition of the Teesport operation of Hodgson Specialty Chemical Division of BTP plc for approximately \$14 million. The Teesport facility was completed in 1991 and served as a custom manufacturing and oilfield chemicals plant. The addition of products that Teesport produced would complement Albemarle's clear completion fluids, amines, and chemicals to the oilfield services industry.

After bidding against Rhodia affiliate International Speciality Phosphates Group (ISPG) for Albright & Wilson (A&W), a maker of nonhalogenated flame retardants, Albemarle U.K. Holdings Ltd. sold its remaining shares (11%) of A&W stock to ISPG, a wholly owned subsidiary of Donau Chemie AG (Chemical & Engineering News, 1999a).

Current Research and Technology

Albemarle continued to improve its vacuum bromine recovery process that initially started up in June 1984, with the installation of a second generation vacuum bromine tower at its Magnolia facility in September 1998 and with the addition of a new bromine production facility in Union County, AR, in July 2000. Albemarle had three facilities in south Arkansas utilizing this patented two-stage vacuum bromine recovery technology consisting of a vacuum streamingout tower and a secondary steam recovery flash chamber. This highly efficient continuous recovery process made Albemarle globally more competitive by reducing bromine production costs and increasing tower capacity from that of prior technology.

Many biologically active agents were derivatives of natural products. A research team specializing in organic synthesis devised a new way to create large combinatorial libraries of such compounds. The new technique, developed by K.C. Nicolaou and coworkers at the Scripps Research Institute and the University of California was unique. A prenylated phenol group was immobilized on a polystyrene-based selenyl bromide derivative resin. The resin would be available commercially from Aldrich Chemical Co., Inc., Milwaukee, WI (Borman, 2000).

A research team at the National Center for Scientific Research of the University of Paris-South and Agfa Gervart Group in Mortsel, Belgium, used a silver bromide dopant to improve the performance of photosensitive silver halide emulsions used to make photographic films. During the conventional photographic process, photons falling on silver halide microcrystals cause the halide ions to generate pairs of electrons and positive holes. The silver ions capture the electrons and the resulting neutral silver atoms group into clusters of metallic silver that form the latent image. This image was then developed into a visible image. This theoretical limit is one silver atom per absorbed photon. With the new dopant, formate ions produce carbon dioxide radicals that transfer energy to silver cations. The overall process is known as photo-induced bielectronic transfer because two electrons are generated. The bielectronic nanosilver halide system leads to the highest light efficiencies ever measured. All the light energy is used to produce the latent image without fogging the film (Chemical & Engineering News, 2000).

Researchers at Eastman Kodak in Rochester, NY, and at Arizona State University developed a photosensitization

process that could double the speed of photographic materials. In the Kodak process, an additional electron donor molecule reacts with the oxidized dye forming a radical cation. This cation undergoes irreversible fragmentation to produce a radical that donates a second electron to the silver halide. The increase in sensitivity of silver halide allows more freedom in designing photographic systems (Freemantle, 2000).

A team that included specialists in environmental sciences, metallurgical processing, mining, water treatment, and worker health studied extraction technologies at the McDonald gold project near Lincoln, MT. Bromine/sodium bromide was one of five alternative technologies studied to process the gold ore. Using the bromine/sodium bromide process required fewer daily truck shipments than the other four processes studied. The chemical conditions required for gold leaching by the bromide lixivants are strongly acidic (De Voto and McNulty, 2000).

In quantum mechanics, particles are described by spread-out wave functions, seemingly existing in many places at once. A computer made of quantum particles has a built-in parallelism, because quantum calculations can be performed on the particles coexisting states simultaneously. Materials used in nuclear magnetic resonance quantum computers include 2,3-dibromothiophene. When nuclei with spin are placed in a magnetic field, they align themselves either parallel or antiparallel to the field, with a slight excess in the parallel orientation. A pulse of electromagnetic radiation of the right frequency and duration will flip a nucleus. A quantum bit, or qubit, can be set up to exist in the 0 and 1 states at the same time. The first quantum computer of Cory and colleagues of the Massachusetts Institute of Technology consisted of two hydrogen qubits in the molecule 2,3-dibromothiophene (Wilson, 2000).

Outlook

Petroleum.—Demand for bromine as a gasoline additive has declined each year since the EPA issued regulations in the 1970s to reduce and eliminate lead in automotive gasoline. In 1979, the amount of bromine sold for this application reached a peak of 225 Mkg. The rapid decline to 141 Mkg in 1986 was a direct result of the limits on lead in leaded automotive gasoline. The European Community continued discussions to reduce lead levels in gasoline. Bromine in petroleum additives was expected to continue to decline over the long term. Federal laws enacted to encourage alternative forms of power in automotive engines are likely to have a depressive effect on bromine demand. The CAA requires mobile sources, such as cars and trucks, to use the most effective technology possible to control emissions. Electric cars were on the market in California. Newer prototypes of the fuel cell that burns gasoline can double the mileage and thereby decrease emissions by using unleaded gasoline.

Sanitary Preparations.—Bromine was used in indoor swimming pools, hot tubs, and whirlpools. The sanitary preparation field is an area where bromine is safer than its substitutes, because bromine has a higher biocidal activity level for the same amount of product. Growth areas are in the pulp and paper industry, cooling towers, and Government-regulated food-washing applications. Albemarle reported double-digit sales growth of brominated biocides as it replaced chlorine and other products in a variety of applications (McCoy, 1998).

Fire Retardants.—Bromine is a reactive flame retardant in that it enters into chemical reactions with the components of the systems in which it is used. In addition, bromine acts as a synergist with many other fire-retardant materials and so increases the effectiveness of the fire retardant. A new nonbrominated material, a precursor to polybenzoxazole (PBO), which is a polyhydroxyamide that upon heating is converted to PBO, could limit flammability. This could have a major negative effect upon the use of BFRs, especially in airplanes, prisons, submarines, and ships (Chemical & Engineering News, 1999b).

Other Uses.—Use of calcium, sodium, and zinc bromides in well-completion fluids decreased during the 1980s as the domestic petroleum industry suffered a severe recession. In 1997, however, the oil-services sector posted another strong performance. About 95% of calcium bromide produced was used as an oil and gas completion fluid. Oilfield chemicals used in drilling, completion and workover, and production operations remained significantly more profitable internationally than in the United States. With the cutback of petroleum supplies internationally and the rising cost of energy for automobiles and heating, usage is expected to increase as new domestic wells are drilled and existing wells are serviced to become more productive.

References Cited

- Borman, Stu, 2000, Science/technology—Naturally combinatorial: Chemical & Engineering News, v. 78, no. 44, October 30, p. 35-36.
- Chemical & Engineering News, 1999a, Business concentrates—Business roundup: Chemical & Engineering News, v. 77, no. 23, June 6, p. 12.
- 1999b, Letters—Fire-resistant polymers: Chemical & Engineering News, v. 77, no. 20, May 17, p. 6.
- 2000, Dopant boosts AgBr emulsion photosensitivity: Chemical & Engineering News, v. 78, no. 1, January 3, p. 8.
- Chemical Market Reporter, 1999a, Albemarle pushes ahead with multiple bromine projects: Chemical Market Reporter, v. 256, no. 6, August 9, p. 24.
- 1999b, Chemical profile: Chemical Market Reporter, v. 256, no. 8, August 23, p. 37.
- 1999c, Society of Toxicology denounces report on pesticide residues: Chemical Market Reporter, v. 255, no. 13, March 29, p. 20.
- 2000a, Albemarle expands biocides: Chemical Market Reporter, v. 258, no. 17, October 23, p. 7.
- 2000b, Albemarle inks Ferro buy: Chemical Market Reporter, v. 258, no. 1, July 3, p. 5.
- 2000c, Asia brief—Albemarle Corp.: Chemical Market Reporter, v. 257, no. 20, May 15, p. 30.
- 2000d, Climate changes from global warming outlined in report: Chemical Market Reporter, v. 258, no. 3, July 17, p. 17.
- 2000e, Company news—ICL to buy rest of Dead Sea: Chemical Market Reporter, v. 258, no. 21, November 20, p. 3.
- 2000f, Dead Sea Bromine pleads guilty: Chemical Market Reporter, v. 258, no. 6, August 7, p. 7.
- 2000g, Great Lakes adds Aqua Clear: Chemical Market Reporter, v. 258, no. 1, July 3, p. 3.
- Chemical Business Newbase, 1999a, Asia Pacific Chemicals—Fanning the flame—Bromine and its derivatives: Chemical Business Newbase, April 23, 1 p.
- 1999b, Europa Chemie—China bromine booming in Europe: Chemical Business Newbase, March 4, 1 p.
- 1999c, European paint and resin news—Bromine compounds most widely used flame retardants for plastics: Chemical Business Newbase, January 15, 1 p.
- 1999d, Speciality chemicals—Dead Sea Bromine Group: Chemical Business Newbase, March 4, 1 p.
- De Voto, R.H., and McNulty, T.P., 2000, Banning cyanide use at McDonald—An attack on open-pit mining: Mining Engineering, v. 52, no. 12, December, p. 19-27.
- Freemantle, Michael, 2000, News of the week—Doubling film speed, radically: Chemical & Engineering News, v. 78, no. 50, December 11, p. 9.

- Hess, Glenn, 2000, Regulatory watch—Phase out of methyl bromide to impose significant costs on U.S. agriculture: *Chemical Market Reporter*, v. 257, no. 16, April 17, p. 27.
- Hogue, Cheryl, 2001, Evaluating chemical risks facing children: *Chemical & Engineering News*, v. 79, no. 1, January 1, p. 8.
- Industrial Minerals, 1998, Ukraine minerals: *Industrial Minerals*, no. 373, October, p. 41.
- 2000a, Jordan—Agra wins JBC Safi Br contract: *Industrial Minerals*, no. 397, October, p. 16.
- 2000b, Mineral notes—Weifang bromine underway: *Industrial Minerals*, no. 397, October, p. 105.
- 2000c, News & Events—Iodine-bromine plant needs investor: *Industrial Minerals*, no. 399, December, p. 23.
- 2000d, News in brief—Bromine—Atofina expands bromine in France: *Industrial Minerals*, no. 399, December, p. 31.
- 2000e, World of minerals—Israel—DSBG pleads guilty to price fixing: *Industrial Minerals*, no. 396, September, p. 12.
- Johnson, Jeff, 1999, News of the week—Industry to test 1,450-plus chemicals: *Chemical and Engineering News*, v. 77, no. 14, April 5, p. 8.
- Kendall, Tom, 2000, Fertilizers bear fruit: *Industrial Minerals*, no. 398, November, p. 51.
- Lerner, Ivan, 2000, Specialties newsfront—Flame retardant price increases show producer discipline: *Chemical Market Reporter*, v. 258, no. 10, September 4, p. 15.
- Mapleston, Peter, 2000, Additives—EU legislation turns the heat on brominated flame retardants: *Modern Plastics*, v. 77, no. 9, September, p. 56.
- McCoy, Michael, 1998, Biocides succeed despite regulations: *Chemical & Engineering News*, v. 76, no. 46, November 9, p. 21-39.
- Reisch, Marc, 1998, Methyl bromide alternatives pose challenges to producers: *Chemical & Engineering News*, v. 76, no. 45, November 9, 46 p.
- TETRA Technologies, Inc., 2000, Form 10-K FY2000: Securities and Exchange Commission, 80 p.
- U.S. Department of Transportation, 2000, Research and special program administration: *Federal Register*, v. 65, no. 161, August 18, p. 50450-50463.
- Warren, Susan, 2000, A new bromide-brine is much better than oil in Arkansas: *Wall Street Journal*, February 14, p. A1, A14.
- Wilson, E.K., 2000, Quantum computer: *Chemical & Engineering News*, v. 78, no. 45, November 6, p. 35-39.

GENERAL SOURCES OF INFORMATION

U.S. Geological Survey Publications

- Bromine. Ch. in *Mineral Commodity Summaries*, annual.
- Bromine. Ch. in *Minerals Yearbook*, annual.
- Evaporites and Brines. Ch. in *United States Mineral Resources*, Professional Paper 820, 1973.

Other

- Bromine. Ch. in *Mineral Facts and Problems*, U.S. Bureau of Mines Bulletin 675.

TABLE 1
SALIENT BROMINE AND BROMINE COMPOUNDS STATISTICS 1/

(Thousand kilograms and thousand dollars)

	HTSUS 2/ number	1996	1997	1998	1999	2000
United States:						
Bromine sold or used: 3/						
Quantity		227,000	247,000	230,000	239,000	228,000
Value		\$150,000	\$111,000	\$162,000	\$201,000	\$206,000
Exports: 4/ 5/						
Elemental bromine: 2801.30.2000						
Quantity		2,920	2,330	1,490	2,110	1,870
Value		\$3,970	\$3,590	\$3,440	\$2,430	\$2,560
Bromine compounds: 6/ (7/)						
Gross weight		13,100	10,700	10,200	9,520	9,210
Contained bromine		11,100	9,050	8,550	8,020	7,740
Value		\$22,100	\$21,200	\$18,000	\$16,000	\$26,200
Imports: 4/ 8/						
Elemental bromine: 2801.30.2000						
Quantity		415	1,650	1,200	1,970	5,470
Value		\$305	\$1,200	\$1,060	\$2,110	\$3,730
Bromine compounds:						
Ammonium bromide: 2827.59.2500						
Gross weight		11,700 9/	33,000 9/	471 10/	1,510 10/	48,100
Contained bromine		9,370 9/	2,690 9/	384	1,240	3,930
Value		\$9,580 9/	\$22,000 9/	\$1,280 e/	\$1,940	\$22,000
Calcium bromide: 2827.59.2500						
Gross weight 10/		--	803	350	--	7,860
Contained bromine		--	642	280	--	6,280
Value		--	\$289	\$213 e/	--	\$4,780 e/
Potassium bromate: 2829.90.0500						
Gross weight		301 10/	378 10/	141	373	245
Contained bromine		144 10/	181	67	178	117
Value		\$1,140 10/	\$1,650 r/	\$571	\$1,470	\$1,100
Potassium bromide: 2827.51.0000 11/						
Gross weight		733 10/	705 10/	910 10/	1,170	871 10/
Contained bromine		493	474	611	786	585
Value		\$1,780	\$1,710	\$2,220 e/	\$2,830 e/	\$2,130
Sodium bromate: 2829.90.2500						
Gross weight		1,200	1,220	1,100	1,050	1,160
Contained bromine		634	646	584	554	615
Value		\$3,030	\$3,170	\$2,900	\$2,430 e/	\$2,750
Sodium bromide: 2827.51.0000 11/						
Gross weight 10/		1,240	2,730	3,960	4,640	3,130
Contained bromine		965	2,120	3,070	3,600	2,430
Value		\$1,910	\$4,210	\$6,090 e/	\$5,540 e/	\$4,820 e/
Other compounds: 2903.30.1550						
Gross weight		6,520	8,910	8,990	7,400	7,760
Contained bromine		5,090	6,900	6,770	785	582
Value		\$14,900	\$16,700	\$18,900	\$17,000	\$15,500
World production e/		483,000	542,000	520,000 r/	550,000 r/	542,000

e/ Estimated. r/ Revised. -- Zero.

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

2/ Harmonized Tariff Schedule of the United States.

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

4/ U.S. Census Bureau.

5/ Export values are free alongside ship (f.a.s.).

6/ U.S. Census Bureau. Includes methyl bromine and ethylene dibromide.

7/ Data for these compounds are derived from HTSUS numbers 2903.30.0500, 2903.30.1500 (1996, 1997, 1998, and 1999), and 2903.30.1520 (2000) information.

8/ Import values are cost, insurance, and freight (c.i.f.).

9/ The respective data for "bromides/bromines and oxides" of ammonium, calcium, and zinc are combined and reported here; imports for 1996 included 568 thousand kilograms, and imports for 1997 included 83 thousand kilograms of zinc bromide.

10/ The Journal of Commerce Port Import/Export Reporting Service.

11/ Bromides of sodium or of potassium import data are usually reported by a mutual HTSUS number, 2827.51.0000.

TABLE 2
ELEMENTAL BROMINE-PRODUCING PLANTS IN THE UNITED STATES, 2000

State and company	County	Plant	Production source	Capacity 1/ (million kilograms)
Arkansas:				
Albemarle Corp.	Columbia	Magnolia (a)	Well brines	
Do.	do.	Magnolia (b)	do.	140 2/
Do.	Union	Maryville	do.	12
Great Lakes Chemical Corp.	do.	Newell 3/	do.	25
Do.	do.	South	do.	
Do.	do.	El Dorado	do.	93 2/
Do.	do.	West	do.	59
Michigan, Dow Chemical Co.	Mason	Ludington 4/	do.	20
Total				349

1/ Actual production capacity is limited by brine availability.

2/ This represents the cumulative capacity of the two identified plant sites.

3/ Closed yearend 1999.

4/ Bromine produced at this plant is reprocessed in Arkansas.

TABLE 3
YEAREND 2000 PRICES FOR ELEMENTAL BROMINE AND SELECTED COMPOUNDS

Product	Value (cents)	
	Per pound	Per kilogram
Bromine:		
Drums, truckloads, works 1/	123	271
Bulk, tank cars, works 1/	56-68	123-150
Bromochloromethane, drums, bulk, f.o.b. Magnolia, AR	127	280
Ethyl bromide, technical, 98%, drums, truckloads	127	280
Ethylene dibromide, drums, carloads	95	209
Hydrobromic acid, 48%, drums, carloads, truckloads, f.o.b.	56	123
Hydrogen bromide, anhydrous, cylinders, 2,500 pounds, truckloads	475	1,047
Methyl bromide, tank cars	77	170
Potassium bromate, granular, powdered, 200-pound drums, carloads, f.o.b. works	179	395
Potassium bromide, N.F., granular, drums, carloads, f.o.b. works	110-112	242-247
Sodium bromide, technical, truckloads	70	154

1/ Delivered prices for drums and bulk shipped west of the Rocky Mountains, 1 cent per pound higher. Bulk truck prices, 1 to 2 cents higher per pound for 30,000-pound minimum.

Source: Chemical Market Reporter. Current Prices of Chemicals and Related Materials, v. 258, no. 25, December 18, 2000, p. 23-28.

TABLE 4
U.S. IMPORTS OF OTHER BROMINE COMPOUNDS 1/ 2/

Compounds	HTSUS 3/ number	1999		2000		Principal sources, 2000
		Gross weight (kilograms)	Value 4/ (thousands)	Gross weight (kilograms)	Value 4/ (thousands)	
Hydrobromic acid	2811.19.3000	250	\$285	370	\$366	Israel, 89%; Germany, 10%; other, 1%.
Ethylene dibromide	2903.30.0500	506	553	2,000	2,020	United Kingdom, 98%; other, 2%.
Methyl bromide	2903.30.1520	2,300	5,000	671	1,690	Israel, 100%.
Dibromoneopentyl glycol	2905.50.3000	1,470	4,890	1,390	4,640	Do.
Tetrabromobisphenol A	2908.10.2500	752	1,380	700	1,030	Do.
Decabromodiphenyl oxide and octabromodiphenyl oxide	2909.30.0700	2,120	4,920	2,630	5,800	Do.
Total		7,400	17,000	7,760	15,500	

1/ These data detail the information included in table 1, imports of "Other bromine compounds."

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

3/ Harmonized Tariff Schedule of the United States.

4/ Declared cost, insurance, and freight valuation (c.i.f.).

Source: U.S. Census Bureau.

TABLE 5
WORLD BROMINE ANNUAL PLANT CAPACITIES AND SOURCES, DECEMBER 31, 2000 1/

Country and company	Location	Capacity (thousand kilograms)	Source
Azerbaijan, Neftechala Bromine Plant	Baku	4,000	Underground brines.
China, Laizhou Bromine Works	Shandong	30,000	Do.
France:			
Atochem	Port-de-Bouc	12,000	Seawater.
Mines de Potasse d'Alsace S.A.	Mulhouse	2,300	Bitterns of mined potash.
India:			
Hindustan Salts Ltd.	Jaipur		Seawater bitterns from salt production.
Mettur Chemicals	Mettur Dam	1,500	
Tata Chemicals	Mithapur		
Israel, Dead Sea Bromine Co. Ltd.	Sdom	190,000	Bitterns of potash production from surface brines.
Italy, Societa Azionaria Industrial Bromo Italiana	Margherita di Savoia	900	Seawater bitterns from salt production.
Japan, Toyo Soda Manufacturing Co. Ltd.	Tokuyama	20,000	Seawater.
Spain, Derivados del Etilo S.A.	Villaricos	900	Do.
Turkmenistan:			
Nebitag Iodine Plant	Vyshka	3,200	Underground mines.
Cheicken Chemical Plant	Balkan	6,400	Do.
Ukraine, Perekopskry Bromine Plant	Krasnopercopsk	3,000	Do.
United Kingdom, Associated Octel Co. Ltd.	Amlwch	30,000	Seawater.

1/ Excludes U.S. production capacity. See table 2.

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

(Thousand kilograms)

Country 3/	1996	1997	1998	1999	2000
Azerbaijan	2,000	2,000	2,000	2,000	2,000
China	41,400	50,100	40,000	42,000 r/	45,000
France	2,024 4/	1,974 4/	1,950 4/	2,000	2,000
India	1,500	1,500	1,500	1,500	1,500
Israel	160,000	180,000	185,000	185,000	185,000
Italy	300	300	300	300	300
Japan	15,000	20,000	20,000	20,000	20,000
Spain	100	100	100	100	100
Turkmenistan	102 4/	130 4/	150	150	150
Ukraine	3,000	3,000	3,000	3,000	3,000
United Kingdom	30,600 4/	35,600 4/	35,900 r/ 4/	55,000 r/ 4/	55,000
United States 5/	227,000 4/	247,000 4/	230,000 4/	239,000 4/	228,000 4/
Total	483,000	542,000	520,000 r/	550,000 r/	542,000

r/ Revised.

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

2/ Table includes data available through April 17, 2001.

3/ In addition to the countries listed, several other nations produce bromine, but output data are not reported; available general information is inadequate to formulate reliable estimates of output levels.

4/ Reported figure.

5/ Sold or used by producers.