IODINE

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Two producers of crude iodine supplied about one-quarter of domestic demand in 2001 based on reported figures (table 1). Domestic and imported iodine was consumed in intermediate products prior to being sold to consumers (table 2). Iodine and derivatives find principal uses in pharmaceutical and medical applications, sanitation or disinfectants, animal feed, catalysts, inks, colorants, photographic equipment, and stabilizers. Published prices for crude iodine were unchanged from 2000 (table 3). Imports of crude iodine increased by 5%, and imports of potassium iodide increased by 8% (table 4). End uses for domestic consumption in 2001 decreased because of a lower number of plants reporting. Exports of crude iodine increased by 45% and exports of potassium iodide increased by 9% during 2001 (table 5). Because some exports and imports are in product categories rather than crude products, net imports are not clearly distinguished. In Chile, iodine is a coproduct of sodium nitrate production. Japan produced iodine from brines associated with natural gas production (table 6). World iodine usage was estimated as follows: x-ray contrast media, 23%; iodophors and biocides, 17%; chemicals, 17%, organic compounds, 12%; pharmaceuticals, 8%; human nutrition, 8%; nylon, 6%; animal feeds, 5%; and herbicides 4% (Sociedad Quimica y Minera de Chile SA, 2001).

Legislation and Government Programs

The Defense Authorization Act for Fiscal Year 2002 (Public Law 107-107), which was enacted December 28, 2001, continued the funding of $150 million ($50 million each) of the operation and maintenance accounts of the Army, Navy, and Air Force by the National Defense Stockpile (NDS) Transaction Fund. The law required the sale of authorized commodities that would result in receipts of $100 million during the 5 fiscal years ending September 30, 2004, and $300 million during the 10 fiscal years ending September 30, 2009. The Annual Materials Plan for fiscal year 2002 authorized the disposal of 453,593 kilograms (kg) (1,000,000 pounds) of crude iodine from the NDS classified as excess to the goal (U.S. Department of Defense, 2001, p. 10). Stocks of iodine classified as excess to the goal at the end of fiscal year 2001 (September 30, 2001) were all subject to disposal limits. On October 29, 1999, "Amendment No. 002 to the Solicitation" changed the sale of the 453,593 kg to quarterly sales of 113,398 kg (250,000 pounds). On October 12, 2000, the Defense National Stockpile Center (DNSC) issued "Amendment No. 005 to Solicitation of Offers for Defense Logistics Agency (DLA)-Iodine-003" that changed the dates for offerings to February 21, May 16, and August 15, 2001. On March 5, 2001, the DNSC announced the sale of 9,070 kg (20,000 pounds) at a value of $115,000 ($12.68 per kilogram or $5.75 per pound) (Defense National Stockpile Center, 2001a). On June 8, 2001, the DNSC announced the sale of 61,200 kg (135,000 pounds) at a value of $750,000 ($12.25 per kilogram or $5.56 per pound) (Defense National Stockpile Center, 2001b). On September 7, 2001, the DNSC announced the sale of 13,600 kg (30,000 pounds) at a value of $165,000 ($12.13 per kilogram or $5.50 per pound) (Defense National Stockpile Center, 2001c). At yearend, 83,900 kg (185,000 pounds) was sold valued at $1,030,000, and the excess iodine was 1.69 million kg (Mkg) (3.73 million pounds) valued at $23.7 million ($14.01 per kilogram or $6.35 per pound) (M.L. Dick, Defense National Stockpile Center, written commun., August 21, 2001).

The U.S. Department of Justice's Drug Enforcement Administration (DEA) was considering tougher permit requirements for selling chemicals that can be diverted to illegal drug manufacture. Iodine can be used to produce methamphetamine. U.S. companies are required to get permits from DEA to sell List 1 chemicals, including iodine and 23 other compounds (Chemical & Engineering News, 2000).

The Nuclear Regulatory Commission, the Federal Emergency Management Agency, the U.S. Department of Energy, and the U.S. Department of Health and Human Service purchased about 10,000 potassium iodide pills from NukePills.com. The pills are sold in packages of 14 only over the Internet. Another seller of the pills is Rad-guard.com which sells 200 pills in a bottle. The pills are designed to be taken in the event of a radiological event, such as an attack on a nuclear powerplant or a dirty bomb. The Food and Drug Administration approved over-the-counter sales of potassium iodide in 1982. It recommends that anyone not allergic to iodine exposed to radioactive iodine take one tablet daily for 10 to 14 days. Doctors administering radiation treatment to cancer patients take potassium iodide regularly. After the 1986 nuclear meltdown in the Soviet Union, 30 million people who might have been exposed to radiation took potassium iodide (Boyer and Gertz, 2002).

Recommended daily allowances of iodine were as follows: infants, 16 micrograms (mg); children 1 month to 3 years, 32 mg, and age 3 to 18, 65 mg; and adults over 18 and pregnant or lactating women, 130 mg. A quarter teaspoon of iodized table salt provides 95 mg of iodine. A 170-gram (6-ounce) portion of ocean fish provides 650 mg of iodine. Most people are able to meet their iodine requirements by eating iodized salt, plants grown in iodine-rich soil, seafood, and seaweed (U.S. Department of Health and Human Services, Centers for Disease Control, 2002§[1]).

One of the standards that is used for iodine is set by U.S. Pharmacopeia Convention Inc. (USPC). USPC is a nonprofit, nongovernment agency that promotes the public health by establishing state-of-the-art standards that ensure high-quality

[1]References that include a section twist (§) are found in the Internet References Cited section.

drugs for human and animal use, and it is a major element in drug regulation.

At the UPCS's first national convention, to bring some rational order to the pharmaceutical industry, physicians made a list of safe and effective drugs and published it in 1820 as the U.S. Pharmacopeia (USP). The USP was first revised in 1830 and every 10 years thereafter until 1970; since then, it has been updated every 5 years; after 2002, it is to be revised annually. In 1973, USP purchased the National Formulary (NF) from the American Pharmaceutical Association and combined the NF with the USP. The latest volume, "USP25-NF20," was published in 2001 and included officially recognized standards for drugs and health care technologies (Ember, 2001).

Production

Domestic production data for iodine were derived from a voluntary survey of U.S. operations by the U.S. Geological Survey (USGS). The three companies to which a survey request was sent responded, representing 100% of the total production (tables 1, 6).

In 1987, IOCHEM Corp. began producing iodine by the blowing-out process at a plant 1.2 kilometers (km) east of Vici, Dewey County, OK. IOCHEM, the largest U.S. plant, was owned by the Kita family and Tomen Corp. The majority of production was shipped to Schering AG of Germany under a long-term contract. IOCHEM reported having nine production wells and four injection wells with a total production capacity of 1,400 metric tons per year (t/yr) at Vici.

North American Brine Resources began operating one miniplant at Dover in Kingfisher County, OK, in 1983. In December 1999, the management committee of North American Brine adopted a formal plan to discontinue the business and dispose of its assets. Beard Co., which had a 40% ownership, reported a loss as a result of the discontinued operation. Effective September 15, 2000, the majority of the assets and liabilities of North American Brine were distributed to Beard Co. As of September 30, 2000, Beard's remaining investment in North American Brine was $66,000 (Beard Co., 2000§). In 2001, the miniplant continued operating at an oilfield-injection-disposal site.

Woodward Iodine Corp., which began production in 1977, was purchased by Asahi Glass Co. of Japan in 1984 and sold to Ise Chemical Industries Co. Ltd. of Japan in 1994. Woodward's plant in Woodward County, OK, produced iodine from 22 brine production wells, which used the blowing-out process, and injected waste through 10 injection wells. Mical Specialty Chemicals, Inc. (a subsidiary of Mitsubishi International Corp.), was the exclusive distributor for iodine produced by Woodward.

Consumption

In 2001, estimated end uses, by percentage, for iodine were as follows: sanitation, 45%; animal feed, 27%; pharmaceuticals, 10%; catalysts, 8%; heat stabilizers, 5%; and other, 5%. Other smaller uses included inks and colorants, photographic chemicals, laboratory reagents, production of batteries, high-purity metals, motor fuels, and lubricants (table 2).

A paper presented at the Forum on Iodine Utilization by Tatsuo Kaiho of Mitsui Chemicals Inc., summarized the novel applications for iodine and the compounds used, which include biocide (dimehtyl trisulfide and 3-iodo-2-propynyl butyl carbonate), disinfectant (polyvinylpyrrolidone iodine), mineral supplement for iodine deficiency disease (IDD) [thyroxin and potassium iodide (KI)], liquid crystal display film, iodine-doped polyvinyl alcohol), photo initiator (iodonium salt), and reaction intermediates [sodium iodide, iodine chloride, and iodide (I_2)]. Mitsui Chemicals' new applications of iodine compounds included hydrogen iodide as an etching gas for indium tin oxide, electrochemical regeneration of periodate as a disinfectant, base polymer for iodophors, and hypervalent iodine compounds for research purposes for processing new compounds (Kaiho, 2001).

Commercial crude iodine normally has a minimum purity of 99.5% or 99.8%, depending on the supplier. Impurities are chiefly water, sulfuric acid, iron, and insoluble materials. The U.S. Pharmacopeia (2001, p. 919-921) specifies an iodine content of not less than 99.8%. The Committee on Analytical Reagents of the American Chemical Society allows a maximum of 0.005% total bromine and chlorine and 0.010% nonvolatile matter.

Radiopaque agents are drugs used to help diagnose certain medical problems. They contain iodine, which absorbs x rays. Radiopaque-diagnosed medical problems included biliary tract disorders, brain disorders, cardiac disease, central nervous system disorders, cerebrospinal fluid, disk disease, gastrointestinal (gall bladder) disorders, peritoneal disorders, splenic and portal vein disorders, urinary track disorders, and vascular disease.

Iodine is used in tall oil and rosins as a stabilizer. Tall oil rosins (TORs) are friable glassy material from light yellow up to dark brown color from crude turpentine, extraction of ground timber (wood) by organic solvents, or distillation of crude tall oil. TOR is applied in production of synthetic rubber, rubbers, and plastic and used in skins, varnishes, etc., as a dead flux for tinning and soldering of metals and also for drawing on a surface of the hair of string instrument bows. Crude tall oil originates as tall oil soap, which is separated from recovered black liquor in the Kraft pulping process. The soap is then acidified to yield crude tall oil. The tall oil is fractionated to produce fatty acids, pitch, and rosin. Fatty acids are sold in competition with vegetable fatty acids to producers of detergents, oilfield chemicals, and paints or converted to derivatives, such as dimer acid. Rosin is almost always chemically modified into esters or adducts that are used to make adhesives, inks, and paper size. Inks can be divided into several major categories. The most popular are the rosin esters, which are derivatives of tall oil. Used commonly in gravure and lithographic inks, rosin esters accounted for 34% of resin consumption by volume in 1999. Hydrocarbon resins, widely used in lithographic inks, accounted for 19% to 20% of consumption. Alkyds accounted for 13% but are also used primarily in lithographic applications, while acrylics, which accounted for 9%, are used in both flexographic and gravure printing. Polyamides accounted for 4% of consumption and are used exclusively in flexographic inks. Various other resins accounted for the remaining 21% of consumption. Among ink makers, Sun Chemical Corporation and Flint Ink Corporation together control 50% of the U.S. market. Rosin esters for inks are produced by Hercules Inc., Lawter International Inc., Arizona Chemical Co., Akzo Nobel NV, and Avecia Limited (Boswell, 2001).

Hercules continued the process of divestiture with a definitive agreement to sell its resins business to Eastman Chemical Co. Eastman will acquire Hercules facilities in Jefferson, PA; Middleburg, Netherlands; Stonehouse, United Kingdom; and Urapan, Mexico. Unit operations will be acquired and then operated under contract with Hercules at shared facilities in Savannah, GA, and Franklin, VA (Chang, 2001). International Specialty Products Inc., which had a 9.92% stake in Hercules as well as four members on its board, was seeking to increase its interest to 20% (Sauer, 2001). Hercules planned to cut 3% of its workforce by the second quarter of 2002.

Deepwater Chemicals Inc. (a part of Tomen American Inc.) has been a supplier of iodine derivatives in the United States since 1931. The company specializes in a range of inorganic and organic iodides with custom manufacturing of fine chemicals to meet specific customer requirements. Deepwater supplies iodine derivatives to the agriculture, photography, catalyst, ink and colorants, sanitizers and disinfectant, industrial chemical, pharmaceutical intermediates, and water treatment industries (Deepwater Chemicals Inc., [undated]§).

Perfluoroalky iodides are produced in a variety of chemicals, such as water- and oil-repellent finishes, surfactant, and surface-treatment agents. Another use is in the preparation of a functionally substituted perfluoro (vinyl ether), which is a key monomer for perfluorinated ion-exchange membranes for the industrial chlor-alkali industry.

H&S Chemical Co. Inc. has been a consulting and research and development company since 1983. Iodine speciality chemicals manufactured by the company included more than 20 organic and inorganic compounds. Included in the list is hydriodic acid used in the preparation of inorganic iodides, organic iodides, x-ray contrast intermediates, pharmaceuticals, disinfectant and sanitizer formulations, and analytical analysis. In 1997, the company moved from Cincinnati, OH, 10 miles south to the enterprise zone of northern Kentucky. H&S had three buildings located on 2.3 hectares (5.6 acres) of a 10.1-hectare (25-acre) site (H&S Chemical Co. Inc., 2001§).

Celanese Chemicals Ltd. consists of the Acetyl Products and Chemical Intermediates segments of Celanese AG. Celanese Chemicals was streamlining jobs at its domestic operations, including the plants at Clear Lake and Bay City, TX. About 850 jobs will be eliminated in chemicals, acetate products, and engineering polymers. Hercules also planned a 3% cut in the workforce by June 2002.

In 2001, the American Chemical Society designated an international historic chemical landmark at the DuPont Experimental Station in Wilmington, DE, for work by Wallace H. Carothers that had resulted in the April 1930 discoveries of both neoprene synthetic rubber and the first commercial super polymer, Nylon66. The use of iodine as a catalyst enabled the commercial production of synthetic rubber and is used to stabilize iodine (Raber, 2001; Plastics Historical Society, 2001§).

Prices

Prices for iodine are negotiated on long- and short-term contracts. The average declared cost, insurance, and freight (c.i.f.) value for imported crude iodine was $13.90 per kilogram. The average declared c.i.f. value for iodine imported from Chile was $14.01 per kilogram. The average declared c.i.f. value for imported crude iodine from Japan was $13.73 per kilogram. The average sale price of iodine sold by the DNSC was $12.27 per kilogram ($5.57 per pound). Published yearend U.S. prices for iodine and its primary compounds are listed in table 3. Solicitations for NDS iodine are on a quarterly basis and go out four times a year. Since 1998, only two companies, West Agro Chemical Inc. and H&S Chemical Co. Inc., have purchased stockpile iodine. Producers believe that the large quantities of iodine the NDS offers for sale each year result in depressing the price that producers can ask since they are in competition with 1 million pounds [454 metric tons (t)] of excess stockpile iodine each year (fig. 1).

Foreign Trade

The U.S. Government adopted the harmonized commodity description and coding system as the basis for its export and import tariff and statistical classification systems. The system is intended for multinational use as a basis for classifying commodities in international trade for tariff, statistical, and transportation purposes. It includes resublimed and crude iodine under the same code and a free duty rate. Values that differ significantly could be a result of items being placed in the wrong category (tables 4, 5).

World Review

The worldwide production of iodine in 2001 was estimated to be approximately 19,200 t, of which 10,500 t (55%) was from Chile and 6,100 t (32%) was produced in Japan. The industrial demands of iodine are still increasing, and areas of applications are expanding beyond the established markets, which are as follows: various additives (23%), x-ray contrast media (22%), germicides and disinfectants (17%), catalysts (15%), pharmaceuticals (9%), and other (14%) (Yamabe, 2000).

The World Health Organization developed guidelines for iodine prophylaxis following nuclear accidents. The latest updated guidelines were in 1999. The iodine can be ingested as either KI or potassium iodate (KIO_3). KI is the preferred alternative since KIO_3 has the disadvantage of being a stronger intestinal irritant. There is no decisive difference in shelf life between KIO_3 and KI. If storage conditions are adequate, then the expected shelf life of the tablets is at least 5 years. After 5 years, the iodine content may be checked and the shelf life extended. Adults and children 12 and over should receive 130-mg doses of KI, children 3-12 should receive 65 mg KI, and infants 1 month to 3 years old should receive 32 mg KI (World Health Organization, 1999§).

Chile.—Atacama Minerals Corp. announced on November 30 that its operating partner, ACF Minera S.A., reached production rates of 2 metric tons per day (t/d) of iodine at the Aquas Blancas project in northern Chile to satisfy phase I of the project. The melting and prilling facility was brought online making Aquas Blancas the newest fully integrated Chilean iodine operation. In phase II, ACF will be required to construct mechanical leaching facilities to maximize recovery of all commercial products at the mine. The project is located 100 km from the port of Antofagasta. Current proven/probable reserves are 44 million metric tons (Mt), grading 412 parts per million (ppm) iodine, 22% sodium sulphate, and 2.87 t nitrates. Full operation of Aquas Blancas will produce 1,200 t/yr of iodine, 300,000 t/yr of sodium sulfate, and 100,000 t/yr of nitrate (Clark, 2001§).

Sociedad Quimica y Minera de Chile SA (SQM) was the largest producer of iodine. All production is from caliche ore. The geologic origin of the caliche ore is not clear, but it is thought to be of sedimentary origin. There is 0.5 to 2.5 meters of overburden above the ore. Iodine concentrations vary among mines, but as a reference, SQM extracted 17 Mt of ore in 1999 in Maria Elena and Pedro de Valdivia with an average of 422 ppm iodine. Ore is crushed to one-half inch size and transferred to a leaching plant in vats where nitrate, iodine, and sulfate are extracted. At the Pampa Blanca mine, located in the Sierra Gorda area, the ore is leached in piles to obtain solutions of iodine, which are transported to solar evaporation ponds. SQM produced an intermediate iodine at Pedro de Valdivia, Maria Elena, Pampa Blanca, and Nueva Victoria facilities. The iodine is treated at the Pedro de Valdivia and Nueva Victoria plants to obtain refined iodine that is smelted, prilled, and packed for shipping. SQM has a 50% ownership in AJAY-SQM Group (Sociedad Quimica y Minera de Chile SA, [undated]§). AJAY-SQM Group is the largest producer of iodine basic inorganic and organic derivatives, accounting for around 25% of world production (Martinez, Eduardo, SQM North America Corp., written commun., October 22, 2002).

SQM agreed to buy the nonmetalic mining assets of the Inverraz Group for $140 million. Inverraz's main assets were a nitrate and iodine mine called Compania de Salitre y Yodo de Chile (Cosayach). The negotiations reportedly ended after 7 months of negotiations when, on October 5, 2001, SQM announced that the differences that existed among the two parties prevented a successful agreement (Fertilizer Markets, 2001). On October 26, 2001, Potash Corporation of Saskatchewan Inc. (PCS) acquired approximately 33.5% of SQM's series "A" shares, which represented 18.2% of SQM's total property. The shares were sold by institutional investors that included Chilean Pension Fund Administrators. PCS made additional purchases of shares that represented 20.4% of SQM's total property. PCS, which operated the Yumbes Mine and facilities through its subsidiary PCS Yumbes, confirmed the purchase in a press release (Chile Chemicals, 2001b§). PCS is the world's largest producer of potassium chloride and it is integrated in the production and commercialization of various phosphate and nitrogen fertilizers.

DSM Minera is a 100% owned subsidiary of the DSM Fine Chemicals business of DSM Group of the Netherlands. DSM Minera submitted an environmental impact statement to the Chilean Region I Commission on the Environment for the construction of a new iodine production plant in Pozo Almonte. The new plant will produce iodine derivatives, such as KI and sodium iodide. These derivatives will represent 60% of DSM's total production. The remaining 40% will be exported as pure iodine and produced in the company's Iris-Granja plant in Pozo Almonte. The iodine derivatives will be transported to Arica and Iquique for export. The plant's construction will require an investment of $4 million. Until 1996, DSM Minera owned only 30% of the Iris-Granja plant. The remaining 70% was held by the ACF Minera. In 1997, DSM purchased 70% of ACF Minera, thereby taking control of the plant (Chile Chemicals, 2001a§).

Europe.—An outbreak of foot and mouth disease led to an abnormally high demand for iodine. Antec International Ltd. is the leading supplier for livestock disinfectants, which include the iodine-based product Virudine™ (Industrial Minerals, 2001).

India.—The duty on iodine was reduced to 10% from 25%. The chemical industry has become a major producer and exporter of chemicals in the world partly because of scaling down the import duty on chemicals widely used in the industry (Ministry of Finance of India, 1997§).

Indonesia.—P.T. Lamindo Ekaperdana reported brines containing 100 ppm of iodine. The company planned to build a 250 t/yr iodine plant (Tampi Mariko, P.T. Lamindo Ekaperdana, written commun., 2000).

Japan.—Japan was the world's second largest producer of iodine (table 6). Iodine was manufactured in Chiba, Miyazaki, and Niigata Prefectures; Chiba Prefecture accounted for about 90% of all production in Japan. The following 8 companies operated 11 plants in Japan: Ise Chemical Co., Ltd., 2 plants in Chiba Prefecture and 1 in Miyazaki Prefecture, 300 metric tons per month (t/mo); Kanto Natural Gas Development Co., Ltd. (KNG), Chiba Prefecture, 100 t/mo; Godo Shigen Sangyo Co., Ltd., Chiba Prefecture, 200 t/mo; Japan Energy Development Co., Ltd., Niigata Prefecture, 30 t/mo; Teikoku Oil Co. Ltd., Chiba Prefecture, 50 t/mo; Toho Earthtech, Inc., Niigata Prefecture, 60 t/mo; Nippoh Chemicals Co., Ltd., Chiba Prefecture, 60 t/mo; and Nihon Tennen Gas Co., Ltd., 2 plants in Chiba Prefecture, 100 t/mo.

Sumitomo Chemical Co. and Mitsui announced a $1.6 billion merger targeted for 2003. This would create the largest chemical company in Asia and the fifth largest in the world. Mitsui is a producer of iodine in the United States. Mitsui and KNG have a joint venture (JI Chemicals Inc.) to develop iodine derivative products (Kanto Natural Gas Development Co., Ltd., [undated]).

KNG was established in 1931 and uses the ion-exchange resin and the blowing-out methods to produce iodine. In the ion-exchange resin method, sand and other impurities are removed by precipitation or filtration. The iodine is then separated from the brine by means of an oxidizing agent and collected by adsorption on the ion-exchange resin. The iodine is separated from the resin by elution, crystallized, and refined. The elution of the resin produces a concentrated iodine solution.

The blowing-out method makes use of the ease with which iodine evaporates and is suitable for use with high-temperature brine. After removal of sand and other impurities by precipitation and separation of the iodine using an oxidizing agent, the brine is exposed to air. The iodine evaporates and is then absorbed, crystallized, and refined. The brines average 110 ppm, and the iodine produced is 99.7% pure. International Standards Organization (ISO) 9002 certification was granted in 1995 (Kanto Natural Gas Development Co., Ltd., [undated]).

Nihon was established in 1940, and iodine production began in 1944. In 1969, a new plant was built in Yokoshiba-machi, and in 1973 and 1988, new plants were built in Chiba Prefecture. Equipment for iodine adsorption changed to sloping fluidized bed (SFB) in June 1993. The plants gained ISO 9002 certification in 1996. Iodine is produced by the following two processes: extraction by resins (discussed before) and the SFB developed to pass brine through the adsorption tower without filtration. The elution of the resin produces a concentrated iodine solution. Iodine is crystallized by oxidizers, separated, and refined into a flaked product (Nihon Tennen Gas Co., Ltd., [undated]).

The Forum on Iodine Utilization (FIU), which was created in June 1998 with the cooperation of industrial, governmental, and academic circles, reached 300 members in 1999. The FIU actively promotes the development of the iodine industry by a variety of symposiums on basic research and applications. The fourth FIU symposium was held at Chiba University in 2001. It included 7 talks and 32 poster sessions (Forum on Iodine Utilization, 2001).

IDD occurs in areas where iodine content of foods is very low. Developed countries have recognized the problem and require iodized salt for consumption. A common agenda was established between Japan and the United States in 1996 to promote cooperation on IDD problems. The Japan International Cooperation Agency and the government of Chiba Prefecture started the Assistance for Mongolia Program in 1997 (Irie, 2000).

Russia.—Iodine content ranges between 30 milligrams per liter (mg/l) and 90 mg/l in 20 oilfields of Northern Sakhalin. The highest grade field is the Odoptu field where recovery of the iodine content could produce 30 t/d of iodine (Elena Sabirova, American Business Center, written commun., March 19, 2001).

A deposit was discovered in Tyumen Oblast, 30 km from the city of Tobolsk. The average content of iodine in the brine is 26 mg/l. Production of 300 t/yr to 500 t/yr for 25 years was estimated (Vladimir Spivak, written commun., August 13, 2002).

A foreign investment project was offered at the Troitsk Iodine Plant. An investment of $15.5 million was sought to reconstruct and increase production capacity of iodine and iodine derivatives at the plant (Foreign Investment Promotion Center, [undated]§).

On October 30, the new Land Code of Russia came into force; it represented a significant reform owing to sanction and encouragement given to the creation of private ownership rights to land, including ownership rights to foreigners. The full provisions of the Land Code apply only to certain nonagricultural land that constitutes approximately 2% of Russia's land surface (Moore, 2002).

Turkmenistan.—Iodine is produced in Turkmenistan by State Corporation TurkmenDokunKhimiya at three wholly state-owned iodine plants—the Balkanabad Chemical Plant, the Boyadag State Chemical Plant, and the Hazar State Chemical Plant. The combined iodine nameplate capacity of these plants is about 600 t/yr. In November 2001, TurkmenDokunKhimiya announced a tender for the construction of five new plants with a granulated iodine production capacity of 100 t/yr each or 500 t/yr in total capacity.

The Balkanabad Chemical Plant, formerly the Nebitdagsky Iodine Plant, was commissioned in 1964 and is located at Vyshka in Balkan Velayat. The plant has a nameplate capacity of 255 t/yr of 99% pure iodine but was operating at production of between 5 t/mo and 6 t/mo or 60 t/yr to 72 t/yr. The plant uses the absorption method to extract iodine from brines associated with the Nebit-Dag-Monzhuklinskoe deposit. The brines have an iodine content of between 30 mg/l and 35 mg/l. The plant can also produce iodine derivatives, such as potassium iodide and iodoform.

The Boyadag State Chemical Plant, located near the town of Kumgag in the Balkan Velayat, was opened in 1999. The plant is the smallest of the three state owned plants with an estimated nameplate capacity of 100 t/yr. In 2001, the monthly iodine production was between 4 t/mo and 5 t/mo. The plant produced iodine of 97% to 99% purity and the product is transported to the Hazar plant for processing to 99.5% iodine.

The Hazar State Chemical Plant, formerly known as the Chelekensky Chemical Plant, is located in Balkan Velayat, north of Cheleken City. The plant processes brines associated with the Cheleken deposit that contain between 20 mg/l and 30 mg/l of iodine. The Hazar plant was originally commissioned in the 1930s with an iodine nameplate capacity of 240 t/yr using the absorption method. In the 1980s, a further 110 t/yr of capacity was added raising the current capacity to 350 t/yr. In 2001, production of the plant was between 7 t/mo and 8 t/mo of iodine of 99.5% purity and 5 t/mo of 99% purity.

The Senagatsu joint venture was established in 1998 between Guneykaya Group of Turkey (49%) and the Turkmen Ministry of Water and Minerals (51%). Following the reorganization of the Ministry of Water and Minerals in 1999 to 2000, its share was transferred to the municipality of Ashgabat City. Iodine is produced, processed, and packaged at two facilities at Seyitkerdiri and Kizylarvat in the Balkan district close to iodine rich brines extracted from the Boyadag deposit. The brines contain between 314 milligrams per cubic meter (mg/m^3) and 388 mg/m^3 iodine. The company began production in 1999 with a nameplate capacity of 4,000 t/yr. Three more plants are expected to be completed in 2003. Resublimed iodine produced is 99.5% pure iodine.

Guneykaya Group reported that the main foreign market for its share of production was Russia, where it was used in catalysts and pharmaceuticals. Golden Bridhe of Dubai, United Arab Emirates, is a major exporter of iodine from Turkmenistan. Golden Bridhe signed a contract with TurkmenDokunKhimiya to export 200 t of production in 2002. The company planned to export a total of 300 t of iodine from Turkmenistan during the same year (Roskill Information Services Ltd., 2002, p. 77-80; table 6).

Current Research and Technology

SQM published a book entitled "IODINE, High Performance Chemistry" with the purpose of providing a basic reference for people that may be interested in iodine chemistry (Sociedad Quimica y Minera de Chile SA, 2001). Researchers, consumers, or others interested in a deeper understanding of this element would find this book a useful reference. The purpose of the book is to stimulate interest in new and existing applications for iodine. SQM stated that an award is planned in association with an international chemists' association to be given to theoretical or practical research in iodine chemistry (Eduardo Martinez, SQM North America Corp., written commun., October 7, 2002).

The USGS planned to publish the first national survey of drugs and personal care products in streams in 2002. Possibly in 2002, the USGS also planned to publish measurements from 80 groundwater sources. For these analyses, 95 substances are being measured from thousands of possible chemicals. In a program begun in 1999, the Environmental Protection Agency started working closely with the USGS to do research to assess possible risks from pharmaceuticals and personal care products that end up in the environment. Drugs ingested are excreted in the urine or feces as the same drug or metabolized into bioactive substances that can be converted back to the original drug in sewage treatment plants. Another direct and avoidable source of drugs in water supplies and sediments are antibiotics given to livestock in their feed. During the past decade, chemists began measuring levels in German water supplies and have found levels to be high. For example, the x-ray contrast media iopamidol was measured at 15 parts per billion (ppb) in sewage treatment plant effluent. In German streams, the levels of drugs generally are less than 1 ppb, but in groundwater, the levels of some drugs were higher. There is presently a wide range of drinking water treatment designs. A combination of activated carbon and ozone treatment or nanofiltration provide the highest level of removal of contaminants (Hileman, 2001).

Nonoriented nylon 6, which was doped with iodine in an I_2-KI solution, was aged in environments with different relative humidities. A relative increase in mass of the complex was measured in the 97% relative humidity environments at room temperature and 1 or 2 months aging (Kawaguchi, 2001).

Researchers at The Pennsylvania State University studied the synthesis of anti-inflammatory and antileukemic products using aryl(alkynyl)iodonium salts in new chemical transformations for organic synthesis. An alkaloid, halichlorine, isolated from the sponge *Halichondria okadai Kodata* holds promise for designing anti-inflammatory agents based on the halichlorine structure. Using alkynyliodonium salt chemistry, a synthesis plan is being researched. In separate work, pareitropone, a member of the tropoloisoquinoline alkaloid family of plant metabolites, demonstrates strong antileukemic activity. Research to develop a synthetic pareitropone is underway. These synthesis projects are possible because of the unique electrophilic properties conferred by the hypervalent iodine atom as well as the potent and varied reactivity of the derived alkylidenecarbenes. Application of this chemistry leads to stereochemically and functionally complex materials that can form natural product structures (Feldman and others, 2001).

Alan J. Heeger, Alan G. Macdiarmid, and Hideki Shirakawa received the Nobel Prize in Chemistry in 2000 for the discovery and development of conductive polymers. Hideki Shirakawa, a retired professor from the University of Tsukuba, Japan, developed the field of electrically conductive polymers. Dr. K. Akagi, a former coworker of Dr. Shirakawa, explained the process of producing such compounds with iodine in an electrically conducting polymer to achieve electrical conductivity as comparable with that of producing those with copper and silver. Dr. Akagi reviewed advances in conducting polymers by focusing on polyacetylene, liquid crystalline polyacetylene derivatives, and helical polyacetylene with a screw-shaped structure (Akagi, 2001).

Iodine derivatives synthesized as effective antibacterial and antifungal agents are designed to release iodine slowly to function as biocides. Iodine slow release agents in combination with iodine and such polymers as polyvinlylpyrroliodone-iodine complex (PVP-I) have a shorter release time. An alternative of PVP-I is cyclodextrin-iodine inclusion complex (CDI) formed from cyclodextrin and iodine. CDI has a slow release rate and lasting biocide effects. A water soluble CDI can be prepared by using methylated cyclodextrin (Hagiwara, 2001).

Titanium-tetrahalide-promoted reactions are valuable tools in organic synthesis. Differences in the reactivities of tetrahalides enabled distinct reaction pathways through selection of an appropriate tetrahalide derivative to promote the reaction. Researchers at Mie University in Tsu-shi, Mie Prefecture, Japan, studied titanium tetraiodide (TiI_4) as a reagent for the reductive formation of carbonyl compounds and subsequent reactions with carbonyl compounds. The use of TiI_4, a commercially available and inexpensive chemical, offers a convenient and practical method for selective reactions of organic compounds (Shimizu and Hayakawa, 2001).

Researchers at Tokai University started a 5-year project to develop a practical chemical oxygen-iodine laser (COIL) system for commercial uses. Because of its high-power capability, COIL has been studied as an antimissile laser in the United States. As an industrial laser, COIL has unique characteristics, as follows: the wavelength is ideal for optical fiber delivery, and an external electric power supply is not required because it is a chemical laser. This makes the laser system attractive for such applications as nuclear reactor decommissioning, construction, civil engineering, and other field applications where a high-power electrical supply is difficult to secure (Endo and others, 2001).

Researches at the National Institute of Standards and Technology (NIST) studied trifluoroiodomethane (CF_3I) as a potential replacement for halon 1301 in aircraft fire suppression systems. Before CF_3I can be considered as a potential drop-in replacement, several operational and technical issues must be addressed or re-examined. Preliminary results were encouraging, but more experiments are required to delineate the dispersion of cold and room temperature CF_3I in air. Additional experiments in the NIST cold environmental chamber are required (Yang, Myden, and Manzello, 2001§).

Researchers at F-Tech Inc. (Japan) developed a catalytic system to produce CF_3I that was a practical and cost-effective method for large-scale manufacture. CF_3I was being studied as a replacement for halon 1301 and halon 1211 as a fire extinguishing agent (Tokoyoda and others, 2001).

Researchers at the Japan Atomic Energy Research Institute conducted research and development on a themochemical process to produce hydrogen as part of a program to utilize heat from high-temperature gas-cooled reactors using iodine and sulfur compounds (Jubo and Nakajima, 2001).

Researchers at Misti Chemicals Inc. reported the results of dry etching on indium-tin-oxide film used in electrodes for liquid crystal displays, using hydrogen iodide (HI) gas by inductive coupling plasma. Compared with hydrogen chloride (HCl), the HI gas had a taper angle of 90º C and no photo resist damage. The etching speed of HI was also faster than HCl (Yanagawa, Odazawa, and Sadamoto, 2001).

Researchers at Chiba Institute of Technology studied the tribiological properties of anodic oxide coating of aluminum impregnated with an iodine compounds. The impregnation of the iodine compounds in the micropores of anodic oxide coating lowered the coefficient of dynamic friction and wear loss (Takaya and others, 2001).

Researchers at Massachusetts Institute of Technology devised a coating, hexyl-PVP, that can kill 99% of common disease-causing organisms. PVP is the acronym for polyvinylpyrriodone. The polymer kills bacteria by a powerful chemical-electrical action, a permanent positive charge that destroys bacteria cell walls and membranes. The antibacterial coating could be incorporated during manufacture so that the surface of many products could be permanently sterile (Midfully.org, 2001§).

PVP polymers (PVPP) are dye-receptive agents, binders, complexing agents, detoxicants, film formers, protective colloidals, stabilizers, and suspending agents. The polymers are available in several viscosity grades, ranging from very low to very high molecular weight, giving this family of products great flexibility across a wide range of industries (International Specialty Products Corp., 1999§).

International Specialty Products Corp. (ISP) offers a tablet disintegrator for nonpharmaceutical products that is based on PVPP technology similar to that used by pharmaceutical tablet formulators. The PVPP swells on contact with water, causing rapid tablet breakup and helping soap to quickly dissolve in the wash. ISP is planning a series of blends of PVPP with other disintegratable materials to offer a range of cost and performance options (McCoy, 2000).

Glass slides treated with hexyl-PVP killed 94% to 99% of the staphylococcus organisms. This special coating could be applied to toys, telephones, door knobs, and even surgical equipment to kill most of the common bacteria that cause infection (Mercy Health Partners, 2001§).

Outlook

During the past decade, iodine production capacity in Chile and the United States has doubled, thus ensuring an adequate future world supply. Overall consumption in traditional uses is projected to grow by as much as 2% per year. Uses for iodine in specialty chemicals have remained stable.

Recent developments in digital imaging can produce electronic prints and overhead transparencies without the need for wet processing. Using a digital camera or scanning the film and converting to digital tapes, the images are produced and stored on disks, hard drives, and tapes. Digital imaging is used for recording most sporting events, game shows, and some situation comedies for television broadcast. From 75% to 85% of all televised programs seen during prime time are recorded on 35-millimeter (mm) motion picture film and then transferred to video tape or laser disc for display. Furthermore, the majority of feature films for movie theater presentations are shot and printed on film because of better image quality. A frame of 35-mm color negative film contains about 6.6 million pixels, about 15 times that of the best high-definition television system and 4 times that of the digital systems now in development. Most popular home video rentals have been box office movie hits that were filmed and then transferred to video. In the next decade, future uses of iodine in films and processing could be limited to specialty imaging as digital imagery technology improves and the cost of equipment becomes more affordable.

There are three major markets for traditional conductive polymers—fuel systems, business machines, and wafer and chip handling. The Freedonia Group, Cleveland, OH, projected the domestic conductive polymer market to grow at 6% per year and to reach $1.5 billion in 2002 from a current market of $950 million in 2001. Conductive polymers have lower weight, cost, and design advantages over metals.

New uses of fluoroiodocarbon as halogen replacements may cause increased demand for iodine for fire suppression. More tests need to be completed on the iodated fluorocarbons before they are acceptable, but preliminary tests are promising. Supplemental programs designed to alleviate IDD in China and India are consuming large amounts of iodine. X-ray contrast media, which contain as much as 60% iodine, will continue to grow between 4% and 5% per year. In Chile and Mexico, individual water purification units that use iodine are a new application of a historical purification process. Purification applications could become significant consumers of iodine.

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TABLE 1
SALIENT IODINE STATISTICS 1/

(Thousand kilograms, unless otherwise specified)

	1997	1,998	1999	2000	2001
United States:					
Production	1,320	1,490	1,620	1,470	1,290
Imports for domestic consumption 2/ 3/	6,380	5,960	5,430	5,110	5,370
Exports 2/ 3/	2,760	2,790	1,130	886	1,480
Consumption:					
Reported 4/	4,500	4,100	4,540	3,990	3,620
Apparent 5/	5,140	4,950	5,990	5,560	5,180
Price, imports, average cost, insurance, and freight value 2/ dollars per kilogram	$14.74	$16.45	$16.15	$14.59	$13.94
World, production	15,700	18,600	18,400	19,400 r/	19,200 e/

e/ Estimated. r/ Revised.
1/ Data are rounded to no more than three significant digits, except prices.
2/ Source: U.S. Census Bureau.
3/ Only the crude iodine "content" of the potassium iodide as declared by tables 4 and 5 is incorporated in data or calculations for this table.
4/ Reported by voluntary response to the U.S. Geological Survey from a survey of domestic establishments.
5/ Calculated by using domestic production plus imports minus exports plus adjustments for Government and domestic industry stock changes.

TABLE 2
DOMESTIC CONSUMPTION OF CRUDE IODINE, BY PRODUCT 1/

(Thousand kilograms)

	2000		2001	
Product	Number of plants	Quantity	Number of plants	Quantity
Inorganic compounds:				
Resublimed iodine	11	205	6	91
Potassium iodide	9	496	4	297
Sodium iodide	7	403	5	382
Ammonium iodide	1	W	--	--
Calcium iodate	1	W	--	--
Cuprous iodide	2	W	1	W
Hydriodic acid	3	175	2	W
Potassium iodate	3	94	3	69
Other inorganic compounds	7	799	4	800
Total	24 2/	2,170	16 2/	1,820
Organic compounds:				
Ethylenediamine dihydroiodide	3	176	1	W
Methyl and/or ethyl iodide	2	W	3	W
Povidone-iodine (idophors)	--	--	--	--
Other organic compounds	7	1,640	4	1,800
Total	(2/)	1,820	(2/)	1,800
Grand total:				
Reported consumption 3/	(2/)	3,990	(2/)	3,620
Apparent consumption 4/	(2/)	5,420	(2/)	4,730

W Withheld to avoid disclosing company proprietary data; included with respective "Other inorganic compounds" and "Other organic compounds." -- Zero.
1/ Data are rounded to no more than three significant digits; may not add to totals shown.
2/ Nonadditive because some plants produce more than one product concurrently.
3/ Reported by voluntary response to the U.S. Geological Survey in a survey of domestic establishments.
4/ Calculated by using domestic production plus imports minus exports plus adjustments for Government and domestic industry stock changes.

TABLE 3
YEAREND 2001 PRICES OF ELEMENTAL IODINE AND SELECTED COMPOUNDS

(Dollars)

Elemental iodine/compounds	Value 1/	
	Per kilogram	Per pound
Iodine, crude, drums	19.00-21.00	8.62-9.53
Potassium iodide, U.S.P., drums, 5,000-pound lots, delivered	26.48	12.01

1/ Conditions of final preparation, transportation, quantities, and qualities not stated are subject to negotiations and/or somewhat different price quotations.

Source: Chemical Market Reporter. Current Prices of Chemicals and Related Materials; v. 260, no. 23, December 17, 2001, p. 23-28 and the U.S. Census Bureau.

TABLE 4
U.S. IMPORTS OF CRUDE IODINE AND POTASSIUM IODIDE FOR DOMESTIC CONSUMPTION, BY COUNTRY OF ORIGIN 1/

(Thousand kilograms and thousand dollars)

Material type and country of origin 2/	2000		2001	
	Quantity	Value 3/	Quantity	Value 3/
Iodine, crude:				
Canada	--	--	4	21
Cayman Islands	18	234	--	--
Chile	3,450	49,100	2,990	41,900
China	5	47	--	--
Japan	1,220	18,600	1,850	25,400
Mexico	7	66	20	335
Netherlands	--	--	63	862
Russia	87	1,260	71	947
Switzerland	--	--	18	209
Other 4/	-- r/	-- r/	10	138
Total	4,790	69,400	5,020	69,800
Iodide, potassium: 5/				
Canada	222	3,720	228	3,350
Chile	37	590	33	540
Japan	1	20	1	23
Netherlands	6	99	249	3,410
Other 6/	217 r/	3,230 r/	11	197
Total	483	7,660	522	7,510
Grand total 7/	5,110	77,000	5,370	77,300

r/ Revised. -- Zero.
1/ Data are rounded to no more than three significant digits; may not add to totals shown.
2/ Import information for crude iodine and potassium iodide are reported by HTS numbers 2801.20.0000 and 2827.60.2000, respectively.
3/ Declared cost, insurance, and freight valuation.
4/ Includes Belgium (2001), India, and the United Kingdom (2001).
5/ Gross potassium iodide contains 76% crude iodine.
6/ Includes Brazil (2001), Denmark (2001), France, Germany, Israel (2000), and the United Kingdom (2001).
7/ Elemental iodine content.

Source: U.S. Census Bureau.

TABLE 5
U.S. EXPORTS OF CRUDE IODINE AND POTASSIUM IODIDE,
BY COUNTRY OF DESTINATION 1/

(Thousand kilograms and thousand dollars)

Material type and country of origin 2/	2000 Quantity	2000 Value 3/	2001 Quantity	2001 Value 3/
Iodine, crude/resublimed:				
Canada	69	1160	85	1370
France	45	716	--	--
Germany	597	8,330	972	10,800
India	(4/)	5	--	--
Japan	--	--	78	885
Malaysia	--	--	33	146
Mexico	120	1,630	221	3,080
United Kingdom	68	978	18	234
Other 5/	109	1,780	48	680
Total	1,010	14,600	1,460	17,200
Iodide, potassium: 6/				
Australia	--	--	1	10
France	--	--	7	114
Mexico	8	141	1	15
Netherlands	3	49	1	21
Taiwan	--	--	7	80
Other 7/	11	198	7	212
Total	22	388	24	452
Grand total 8/	1,020	15,000	1,480	17,700

-- Zero.
1/ Data are rounded to no more than three significant digits; may not add to totals shown.
2/ Export information for iodine, crude/resublimed and potassium iodide are reported by HTS numbers 2801.20.0000 and 2827.60.2000, respectively.
3/ Declared "free alongside ship" (f.a.s.) valuation.
4/ Less than 1/2 unit.
5/ Includes Argentina (2001), Belgium (2000), Chile (2001), Colombia (2000), Denmark, the Dominican Republic, El Salvador, Jamaica (2001), the Netherlands (2001), New Zealand (2001), Norway (2000), Peru (2001), Taiwan (2000), Thailand, and Venezuela (2000).
6/ Gross potassium iodide contains 76% crude iodine.
7/ Includes Chad (2001), El Salvador (2001), Germany, Guatemala (2001), Saudia Arabia (2001), Switzerland, Taiwan (2000), Trinidad and Tobago (2001), and the United Kingdom.
8/ Elemental iodine content.

TABLE 6
CRUDE IODINE: WORLD PRODUCTION, BY COUNTRY 1/ 2/

(Thousand kilograms)

Country	1997	1998	1999	2000	2001 e/
Azerbaijan e/	300	300	300	300	300
Chile 3/	7,154	9,722	9,317	10,474 r/	10,500
China e/	500	500	500	500	500
Indonesia	83	65 r/	74 r/	75 r/ e/	75
Japan	6,036	6,142	6,152	6,157 r/	6,100
Russia e/	250	280	300	300	300
Turkmenistan e/	87 4/	90	150	150	150
United States	1,320	1,490	1,620	1,470	1,290 4/
Uzbekistan e/	--	1	2	2	2
Total	15,700	18,600	18,400	19,400 r/	19,200

e/ Estimated. r/ Revised. -- Zero.
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 June 10, 2002.
3/ Includes iodine production reported by Servicio Nacional de Geologia y Minería.
4/ Reported figure.

FIGURE 1
HISTORIC IODINE PRICES