IODINE

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Three producers of crude iodine supplied about 27% of domestic demand (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 1999 (table 3). Imports of crude iodine decreased by 7%, and imports of potassium iodide increased by 65% (table 4). End uses for domestic consumption in 2000 were reported in potassium iodide, which decreased by 26%, and sodium iodide, which decreased by 27%. Exports of crude iodine and potassium iodide were at 1999 levels during 2000 (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).

Legislation and Government Programs

The Annual Materials Plan of the U.S. Department of Defense proposed the sale of 453,593 kilograms (kg) (1 million pounds) of iodine for fiscal year 2000. The National Defense Authorization Act for Fiscal Year 2000 (Public Law 106-65), signed on October 5, 1999, did not change the previous authorization for disposal of all stock of crude iodine in excess of the National Defense Stockpile (NDS) goal. The law authorized the transfers of no more than $150 million from the NDS Transaction Fund equally to the operation and maintenance accounts of the Army, Navy, and Air Force, no more than $50 million each (section 304). Public Law 106-65 also obligated no more than $78.7 million of the NDS transaction fund for the operation of the NDS program. The law required the sale of authorized commodities that would result in receipts of $10 million by the end of fiscal year 2000; $100 million during the fiscal year ending September 30, 2004; and $300 million during the fiscal year ending September 30, 2009. On October 17, 2000, the Defense National Stockpile Center (DNSC) issued “Amendment No. 003 to Solicitation of Offers for DLA-Iodine-003” that changed the dates for offerings to February 21, May 16, and August 15, 2001. 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) and set subsequent offering dates for 1999 and 2000. On January 13, 2000, the DNSC announced the award of 19,050 kg (42,000 pounds) at a value of $270,000 ($14.17 per kilogram or $6.42 per pound). On March 8, 2000, the DNSC announced the sale of 2,270 kg (5,000 pounds) at a value of $31,000 ($13.67 per kilogram or $6.20 per pound). On

Iodine in the 20th Century

Iodine was first produced in the United States between 1917 and 1921 at an experimental station at Summerland in Santa Barbara County, CA. Large quantities of seaweed were harvested and used to produce acetic acid, potash fertilizers, and iodine. Iodine was first exploited commercially in 1916 in the form of potassium iodide as a remedy for goiter. In 1916, tincture of iodine was used as a disinfectant for cuts and abrasions and for sanitation. In 1939, Louis Daguerre published details of his method for making photographs on plated silver by using iodine vapor to form a thin coating of light sensitive silver iodide crystals.

Iodine production from underground brines began in the United States on August 2, 1928, near Shreveport, LA, using a process developed by Dow Chemical Co. The General Salt Co. began extracting iodine in 1928 from oilfield brines in the Signal Hill district in Long Beach, CA, using a charcoal process. The Louisiana plant closed in 1932, and the operation moved to California and was renamed the Jones Chemical Co. Deepwater Chemical Co. produced iodine in California from 1932 until 1960 by the silver iodide process. Domestic production in 1937 was reported to be 136,000 kilograms. In 1938, the Jones plant was incorporated as the Io-Dow Chemical Co. Production in 1940 was 564,000 kilograms. In 1961, Dow closed its plant in California and opened an iodine plant in Midland, MI, using underground brines associated with bromine production. Dow closed its Michigan plant in 1986.

In 1977, Woodward Iodine Corp. began production of iodine in Oklahoma. This plant was purchased by Ise Chemical Industries Co. Ltd. of Japan in 1994. In 1983, North American Brine Resources completed two miniplants in Kingfisher County, OK. In 1987, IOCHEM Corp. opened an iodine plant in Vici, OK. All production in Oklahoma was from gas brines.

In 2000, iodine was consumed in animal feed (45%), pharmaceuticals (27%), catalysts (10%), heat stabilizers (5%), and other applications (5%). About 27% of the iodine consumed during 2000, which was about 1.5 million kilograms, was from domestic production.

June 7, 2000, the DNSC announced the sale of 2,270 kg (5,000 pounds) at a value of $30,000 ($13.23 per kilogram or $6.00 per pound). On August 31, 2000, the DNSC announced the sale of 14,300 kg (31,500 pounds) at a value of $188,000 ($13.21 per kilogram or $5.97 per pound). On December 5, 2000, the DNSC announced the sale of 11,200 kg (25,000 pounds) at a value of $150,00 ($13.23 per kilogram or $6.00 per pound). At yearend, 949,215 kg (108,500 pounds) was sold valued at $670,000, and the excess iodine was 1.7 million kilograms (Mkg) (3.8 million pounds) valued at $28 million ($16.44 per kilogram or $7.46 per pound).

In 1906, the Food and Drug Act was passed to ensure the safety and effectiveness of drugs and to set standards to determine which drugs can be sold over the counter and which ones require a prescription. During 1997 and 1998, online pharmacies were selling drugs to consumers without a valid prescription. Iodine and many of the products made from iodine are controlled substances. To protect consumers from illegal sales of drugs over the Internet, the Executive Office of the President unveiled an initiative in December that would require all online pharmacies to demonstrate that they comply with State and Federal laws and are licensed by the Food and Drug Administration (FDA). The maximum civil penalty would be raised to $500,000 from $1,000. The proposal would give the FDA subpoena power to investigate online pharmacies and provide $10 million to set up a rapid-response team to go after illicit drugs (Hileman, 2000).

One of the standards that is used for iodine is set by U.S. Pharmacopeia (USP). USP is an organization whose work is largely unknown, unrecognized, or overlooked by the public. USP sets and disseminates standards that ensure high-quality drugs for human and animal use, and it is a major element in drug regulation. The very foundation of drug regulation is delegated by statute to this private organization. USP was created in 1820 to bring some rational order to the pharmaceutical industry. At the first national convention, physicians made a list of safe and effective drugs and published this in what is now the USP. The USP was first revised in 1830 and every 10 years thereafter until 1970, when it was updated every 5 years; after 2002, it will 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 (USP24-NF19) was published in 2000 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. 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 the 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, owned by Beard Oil Co. (40%), Godoe Shigen (USA) Inc. (50%), and Mitsui & Co. (USA), Inc. (10%), began operating a miniplant at Dover in Kingfisher County, OK, in 1983. In 2000, the company operated one plant at an oilfield injection-disposal site that obtained brines from about 50 wells in the Oswego Formation. Iodine concentrations were as much as 1,200 parts per million (ppm). Its large plant in Woodward, OK, remained closed pending price increases.

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

Estimated end uses, by percentage, for iodine in 2000 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).

Commercial crude iodine normally has a minimum purity of 99.5%. Impurities are chiefly water, sulfuric acid, iron, and insoluble materials. The USP XVII specifies 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.

Recommended daily allowances of iodine were as follows: infants, 40 to 40 micrograms (mg); children age 1 to 3 years, 70 mg, age 4 to 6 years, 90 mg, age 7 to 10 years, 120 mg, and age 11 and up, 150 mg; pregnant women, 175 mg; and lactating women, 200 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 (Yahoo! Health, 2000, Iodine in diet, accessed October 30, 2000, at URL http://health.yahoo.com/health/diseases_and_conditions/disease_feed_data/iodine_in_diet).

In the human fetus, thyroid hormone is essential for the development of the central nervous system. The lack of thyroid hormone causes cretinism, which results in severe mental retardation and somatic growth. Until the 12th week of life, the sole source of thyroid hormone supply is maternal thyroid hormone. Recently, it was reported that the mild deficiency of thyroxine in maternal blood in the first or the second trimester of pregnancy would cause the impairment of cognitive capabilities of the offspring measured at 4 to 7 years after birth (Shishiba, 2000).

Arizona Chemical Division, which is a subsidiary company of International Paper Co., is a leading producer of pine chemicals that include tall oil and rosins, which use iodine as a stabilizer. These pine products were used globally for a variety of end uses, including adhesives, chewing gum, inks and coating, lubricants, rubber, plastics soaps and cleaners, and other markets (Arizona Chemical, July 26, 2000, Arizona Chemical launched new Internet site, accessed August 14, 2000, at URL http://www.arizonachemical.com/press/press_internet_7-26-00.htm).

International Paper put its Arizona Chemical pine chemical business up for sale as one part of a divestment program. Arizona Chemicals, headquartered in Jacksonville, FL, celebrated its 70th anniversary on February 8 (Chemical Market Reporter, 2000b). With about $700 million per year in sales, Arizona Chemical is the world's largest pine chemical company, fractionating tall oil and turpentine into chemicals for the adhesive coatings and inks industries (Chemical & Engineering News, 2000).

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. The pulp and paper industry is mature, and companies are increasingly pulping younger farmed pine trees that have a lower chemical content. The use of recycled fiber has reduced the growth of Kraft pulp production, and hardwood pulping yields no tall oil. Some tall oil derivative customers that use adhesives have shifted from rosin to hydrocarbon resins to ensure adequate supplies. Because of increases in crude oil prices, many of those hydrocarbons have faced significant pricing pressure (Naude, 2000).

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. Hercules Inc. is the only company in the United States still extracting rosin and turpentine from aged pine stumps. Akzo and Hercules compete with products from China, because certain customers require the white high-purity rosins derived from Southeastern U.S. pine gum. Georgia-Pacific completed a 50% expansion of its tall oil fractionation capacity in Crossett, AR, reducing the amount of tall oil it sells on the merchant market. Westvaco Corp. is the fourth largest tall oil producer making speciality adhesive (McCoy, 2000).

Hercules acquired the pulp and paper division of Quaker Chemical Corp. The business generates $8 million per year in revenues and provides specialty chemicals for tissue papermaking and pulping processes (Chemical Market Reporter, 2000b). Hercules announced that it entered into discussions to sell its pine and hydrocarbon resin business to an unidentified "major company." Hercules sells about $450 million per year of resins and has 1,500 employees. Its product line is divided between resins made by refining crude tall oil, a byproduct of making paper from pine trees, and resins made from the 5- and 9-carbon hydrocarbons fractions that are produced in ethylene plants (McCoy, 2000). Eastman Chemical Co. announced its intent to purchase Hercules Inc.'s hydrocarbon resins business and select portions of its rosins resins business (Chemical Market Reporter, 2000a).

Radiopaque agents are drugs used to help diagnose certain medical problems. They contain iodine, which absorbs x rays. Radiopague-diagnosed medical problems include 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.

Perfluoroalky iodides are produced in a variety of chemicals, such as water and oil repellent finishes, surfactants, 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. The amount of iodine used for these intermediates was expected to consume 1,500 metric tons (t) of world production in 2000 (Yamabe, 2000).

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 $14.58 per kilogram. The average declared c.i.f. value for iodine imported from Chile was $14.38 per kilogram. The average declared c.i.f. value for imported crude iodine from Japan was $15.26 per kilogram. The average sale price of iodine sold from the DNSC was $16.44 per kilogram ($7.46 per pound). Published yearend U.S. prices for iodine and its primary compounds are listed in table 3.

Since 1977, when the first U.S. plant was built in Oklahoma, iodine c.i.f. prices per kilogram have been as follows: 1977, $4.39; 1978, $4.72; 1979, $6.57; 1980, $13.80; 1981, $13.12; 1982, $12.92; 1983, $12.06; 1984, $10.58; 1985, $11.86; 1986, $12.52; 1987, $15.26; 1988, $17.46; 1989, $17.67; 1990, $15.19; 1991, $10.16; 1992, $9.03; 1993, $7.90; 1994, $7.56; 1995, $9.88; 1996, $12.90; 1997, $14.66; 1998, $16.45; and 1999, $16.15. U.S. production decreased to 1.5 Mkg from 1.6 Mkg, and world production remained at 18 Mkg in 2000.

Iodine prices are stable compared to the volatility experienced during the 1980s and 1990s. In the second half of the 1980s, iodine prices increased as a result of strong demand and reduced supply owing to fire damage at iodine production facilities in Chile. Demand and prices decreased between 1990 and 1991. New capacity in Chile during 1996 and 1997 combined with increased sales from the DNSC caused an oversupply of iodine and a price decrease (Mineral Price Watch, 2001).

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 2000 was estimated to be approximately 18,000 t, of which 9,100 t (51%) was from Chile, and 6,100 t (34%) 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).

Azerbaijan.—This nation's economy is based on oil and natural gas production; oilfield brines contained iodine and bromine. Enterprises and individuals engaged in mineral extraction are subject to a mineral fields or subsoil tax. The tax is applied to the net income received from the sale of the product at rates ranging from 3% to 26%. According to the list approved by the Cabinet of Ministers in June 1996, the tax is applied to iodine and mineral water (Oil and Gas Chemistry, 2000).

The Neftchala iodine-bromine plant in Neftchala planned to conduct a tender to attract investment to modernize production to include production of potassium iodide and other iodine derivites. Investment of $1.4 million over 1.5 years is required. A production line for iodine-containing salt with a capacity of 100,000 t/yr has been constructed and commisssioned. The iodine is recovered from brines associated with the Neftchala and Khillinsky oilfields in the Prikurinsky Basin. The plant design capacity is 800 t/yr of iodine but is presently idle because of the need for capital for repairs (Industrial Minerals, 2000).

Chile.—Chile was the leading producing country of iodine. In response to falling prices and demand, Compania de Salitre y Yodo reduced its iodine output to 2,000 t/yr from 2,400 t/yr. DSM Mineraa SA cut production at the Iris-La Granja site by 30% in 1999. Sociedad Química y Minera de Chile SA (SQM) continued to idle two units.

Atacama Minerals Chile SCM, a subsidiary of Atacama Minerals Corp., Vancouver, Canada, finalized an agreement with ACF Minera S.A. to develop the Aguas Blancas project near Antofagasta, Chile. The agreement includes plans for a larger capacity heap-leach operation to allow for production of 720 t/yr. Once the iodine facilities are operational, the plant will begin production of the potassium nitrate and sodium sulfate reserves (Mining Engineering, 2000).

The nitrate and iodine project at Pampa Dominador was being developed by Minera CeroImán SCM (MCI), a wholly owned subsidiary of Minera Soledad S.A., a Chilean private company established in 1988. The deposit is located within the Atacama Desert at an altitude of 1,750 meters (m) and 160 km southeast of the Pacific port of Antofagasta. The site is the location of the former Oficina Salitrera Dominador, which operated from 1925 to 1930. A total of 8,750 hectares (ha) of MCI's mining property at Pampa Dominador is the main deposit for the nitrate and iodine project. An export program that covered about 5,000 ha was carried out during 1998. Nine ore bodies with average ore strata thickness of 2 m and overburden thickness averaging 0.6 m were defined. Reserves calculated to January 1999 included proven reserves of 540 Mkg of iodine with probable reserves of 620 Mkg iodine (Minera CerroImán, 2000).

The Potash Corporation of Saskatchewan, Inc. (PCS) began production from the Yumbes Mine in July. About 18 t of iodine was shipped from the mine to the United Kingdom. Planned production will include 40 t/yr of iodine. PCS has put about $14 million into the projet since acquiring the project for $36 million in 1999 (Green Markets, 2000).

Cosayach S.A. was preparing to begin production of nitrates at its operation near Poao Almonte in the northern Chile. Production also included limited amounts of iodine (Fertilizer Week, 2000).

All of SQM's production was from surface mines at Pedro de Valdivia and Maria Elena and from mine tailings at Sierra Gordo. Exports of 80% of the iodine produced go to the following areas: Europe (40%), the United States (27%), South America (21%), Asia (7%), and Africa (5%) (Eugenio Ponce, International Fertilizer Industry Association, 1998, Chile—Specialty fertilizers and industrial chemicals from two unique resources, accessed May 23, 2001, at URL http://www.fertilizer.org/publish/biblio/biblio99/conf4.htm).

Three of SQM's top officials were fined a total of $32,000 by Chile's Superintendencia de Valores Y Seguros (SVS). The SVS alleged that the president of Ora Blanco did not inform the Commission that they had set up two companies that held ultimate control of SQM. Patco Trust and Holywell Trust were registered in the British Virgin Islands in 1994 but were not declared to the SVS until 1999 (Industrial Minerals, 2001).

All iodine processed in Chile uses sulfuric acid. The use of a sulfuric-acid-nitrate mixture could generate fumes and leakages, with inherent risk to the workers. Sulfur melting and sulfur dioxide generation was performed using the same technology in all Chilean plants. Only the age of the plant makes the difference in emissions to the atmosphere. Using kerosene in a solvent extraction process puts plants at increased risk of fire (Munoz, 2000).

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,1997, Public finance—Tax measures, accessed January 17, 2001, at URL http://finmin.nic.in/indiabudget/es97/CHAP2.htm).

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 during 1999: 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 in Chiba Prefecture, 100 t/mo.

Sumitomo Chemical Co. and Mitsui Chemicals Inc. announced a $1.6 billion merger targeted for 2003. This would create the largest chemical company in Asia and 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.).

KNG was established in 1931 and uses the ion-exchange resin and the blowing-out method 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, then is crystallized and refined. 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.).

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 Perfecture. Equipment for iodine adsorption changed to sloping fluidized bed (SFB) in June 1993. The plant gained ISO 9002 certificiation in 1996. The iodine was produced by two processes: the 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 and is separated and refined into a flaked product (Nihon Tennen Gas Co., Ltd.).

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 third FIU symposium was held at Chiba University in 2000. It included 17 talks and 30 poster sessions.

Iodine deficiency disorder (IDD) occurs in areas where iodine content in food is very low. Developed countries have realized the problem and require iodized salt for consumption. In 1986, a representative of Japan attended the International Council for Control of Iodine Deficiency Disorder's inaugral meeting in Nepal. 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).

Recent studies on iodine in brines from the late Pliocene age (a period between 5 and 1.8 million years ago) in Kazusa Formation in Chiba, Japan, showed that the iodine orginated during the Palaeogen age, a period in the Cenozoic Era between 65 to 54 million years ago, which is much older that the layers in which the brines occur. The results might indicate that iodine in these brines is not derived from the reservoir formation but is released from marine sediments undergoing subduction in this region (Muramatsu, 2000).

Russia.—Iodine content ranges from 30 to 90 milligrams per liter in 20 oilfields of Northern Sakhalin. The highest grade field is the Odoptu field where recovery of the iodine content could produce 30 metric tons per day of iodine (Elena Sabirova, American Business Center, written commun., March 19, 2001).

Turkmenistan.—Iodine is produced in Turkmenistan and Azerbaijan from underground brines. The Nebitdag plant was in Vyshka, 26 km southwest of Nebitdag City in Balkan Velayat. The plant extracts bromine and iodine from underground brines of the Nebitdag-Monjoukley deposit. The plant reported production capacities of 255 t/yr of iodine and 3,200 t/yr of ferrous bromide, as well as 1,300 t/yr of bromine derivatives and 100 t/yr of sodium hypochlorite. It was commissioned in 1969 and had 33 employees (table 6).

Current Research and Technology

Three scientist received the Nobel Prize in Chemistry for developing the important new field of electrically conductive polymers. The polymer was produced in 1977. By doping polyacetylene with iodine, the polymer film conductivity increased. On exposure to iodine, polyacetylene is oxidatively doped, and the polymer chain loses an electron, leaving a hole or positive charge. When the hole is filled by an electron jumping from a neighboring position, a new hole is created. As the cascade continues, the positive charge can migrate down the conjugated chain (Dagani, 2000).

Researchers at the Massachusetts Institute of Technology devised a coating, hexyl-PVP, that can kill 99% of common disease-causing organisms. PVP is the acronym for polyvinylpyrrolidone. The polymer kills bacteria by a powerful chemical-electrical action, a permanent positive charge that destroys bacterial 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, May 22, 2001, Hexyl-PVP special coating kills germs, researcher says, accessed June 28, 2001, at URL http://www.mindfully.org/Plastic/Hexyl-PVP-Kills-Germs.htm).

PVP polymers (PVPP) are dye-receptive agents, binders, complexing agents, detoxicants, film formers, stabilizers, protective colloidal, 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, PVP polyvinylpyrrolidone polymers, accessed January 22, 2001, at URL http://www.ispcorp.com/products/industrial/ind11.html).

International Specialty Products Corp. (ISP) offers a tablet disintegrantor 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 dissolve quickly in the wash. ISP is planning a series of blends of PVPP with other disintegrant materials to offer a range of cost and performance options (McCoy, 2001).

Researchers at the Chiba Institute of Technology developed an aluminumoxidation coating impregnated with an iodine compound by an electrochemical method. The bactericidal activities of the coating were effective against various molds and bacteria (Takaya, 2000).

The adsorpiton of iodine on single crystal electrodesis is one of the most intensively studied electrochemical processes. Recent studies at Tohoku University disclosed a novel property of iodine-modified electrodes because the adsorption of organic molecules formed highly ordered molecular arrays. The internal molecular structure, orientation, and packing arrangement were clearly visualized with near-atomic resolution by in situ scanning tunneling microscopy (Itaya, 2000).

Hydrogen iodide gas showed superior characteristics for etching materials, such as indium tin oxide (ITO) film, used for pixel electrodes of liquid crystal displays. Although wet etching is still the major process for ITO etching, the dry etching process makes sharper etching compared with other gases (Sadamoto and others, 2000).

Iodine-125 is the primary radionuclide for in vitro application due to its 60 day half-life and low energy photon emission. The long half-life permits the preparation of radioimmunoassay and immunometric radioassay. Iodine-123 has good imaging properties for planar and single-photon emission computed tomography imaging. Its physical properties include a half-life of 13 hours. Iodine-131 has a relatively long half-life (8 days) and emits both gamma and beta rays, which render this radionuclide useful for in vivo radiotherapy of cancer and Basedow's goiter. Iodine-123 and iodine-131 also are applied to label such proteins as antibodies against tumor cells for both external imaging and targeted radiotherapy. Monoclonal antibodies have been used to deliver radionuclides to target tissues for diagnostic and therapeutic purposes. The use of radiolabeled intact antibodies has shown limitations, such as slow penetration into tumors. Studies at Chiba University indicated that an iodine organic reagent (HML) would be a promising reagent for targeted imaging and therapy using antibody fragments as vehicles. These studies suggested that radiochemically designing antibody fragments that liberate radiometabolites of urinary excretion by the action of brush border enzymes may constitute a new strategy for reducing the renal radioactivity levels of antibody fragments (Arano, 2000).

Chemists at the Massachusetts Institute of Technology found that a chiral catalyst derived from 4-pyrrolidinopyridine and O-acylated azlactone exhibits the correct reactivity for catalytic kinetic resolution of racemic primary amines. The iodine catalyst reacts more rapidly with the catalyst than the amine, allowing the catalyst to exert its chiral influence before the reaction is complete (Chemical & Engineering News, 2001).

Evergreen Nylon Recycling llc (ENR) was named Recycler of the Year by the Plastics Recycling Division of the Society of Plastics Engineers. ENR is a joint venture of Honeywell International Inc. and DSM Chemicals North America Inc. The company converts postconsumer nylon-6 carpet and other nylon-6 waste that required iodine compounds as a stabilizer during manufacturing into caprolactam, the raw material for nylon-6. Type 6 nylon is used in products that include automotive parts, residential and commercial carpets, engineered plastics, films, packaging, and sporting goods (Reese, 2000).

At the 198th meeting of the Electrochemical Society in Phoenix, AZ, 1,200 scientific presentations were presented, including one on the use of lithium-iodide batteries. The plenary lecture focused on electrochemistry in the service of medicine. The vice president of research and development at battery manufacturer Wilson Greatbatch, Clarence, NY, gave an overview of power sources used in implantable medical devices. Nearly all pacemakers being implanted today run on lithium-iodide batteries, and the cells are extremely stable with some real-time tests showing these batteries running continuously for nearly 25 years. The life expectancy of the battery is determined by its size (Jacoby, 2000).

Chemists at the University of Lausanne, Switzerland, have invented an asymmetric carbon-carbon bond-forming reaction that could be useful in synthesis. Methyl iodide is used in part of the reaction (Stinson, 2000).

Scientists at the National Institute of Radiological Science (Japan) and Geochemisches Institut (Germany) analyzed 300 rocks and major units and subunits of the Earth's crust for iodine. The high average concentrations were 30 ppm of iodine in deep-sea carbonates and 2.5 ppm iodine in continental limestones. Seawater averaged 50 parts per billion iodine (Muramatsu and Wedepohl, 1998).

At a session of the American Chemical Society's national meeting in San Francisco in March 2000, European researchers presented data confirming that a wide variety of drugs and their metabolites are showing up in low concentrations in waterways of Croatia, Germany, Greece, and Switzerland. One of the pharmaceuticals identified in the environment is iopromide, an x-ray contrast media. Pharmaceuticals and personal care products can end up in the environment if not properly disposed. In the United States, the topic falls within the regulatory responsibilities of the U.S. Environmental Protection Agency and the Food and Drug Administration (Zurer, 2000).

Outlook

During the past decade, iodine production capacity in Chile and the United States has doubled, thus ensuring an adequate future world supply. Overall growth 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. By using a digital camera or scanning the film and converting to digital tapes, the images are produced and stored on disks, hard drives, and tape. 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.

New uses of fluoroiodocarbon as halogen replacements may cause an increased demand for iodine. More tests need to be completed on the iodated fluorocarbons before they are acceptable, but preliminary tests are promising. Supplemental programs designed to alleviate iodine deficiency disorder 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)

	1996	1997	1998	1999	2000
United States:					
Production	1,270	1,320	1,490	1,620	1,470
Imports for domestic consumption 2/ 3/	4,860	6,380	5,960	5,430	4,790
Exports 2/ 3/	2,410	2,760	2,790	1,130	886
Consumption:					
Reported 4/	3,920	4,500	4,100	4,540	3,990
Apparent 5/	3,700	5,140	4,950	5,990	5,420
Price, imports, average c.i.f. value, dollars per kilogram 2/	$12.82	$14.74	$16.45	$16.15	$14.59
World, production	14,100 r/	15,700 r/	18,600 r/	18,400 r/	18,000 e/

e/ Estimated. r/ Revised.
1/ Data are rounded to no more than three significant digits, except prices.
2/ 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)

	1999		2000	
Product	Number of plants	Quantity	Number of plants	Quantity
Inorganic compounds:				
Resublimed iodine	9	196	11	205
Potassium iodide	9	676	9	496
Sodium iodide	7	373	7	403
Ammonium iodide	1	W	1	W
Calcium iodate	2	W	1	W
Cuprous iodide	2	W	2	W
Hydriodic acid	4	177	3	175
Potassium iodate	3	70	3	94
Other inorganic compounds	6	367	7	799
Total	(2/)	1,860	(2/)	2,170
Organic compounds:				
Ethylenediamine dihydroiodide	4	877	3	176
Methyl and/or ethyl iodide	3	68	2	W
Povidone-iodine (idophors)	4	645	--	--
Other organic compounds	8	1,090	7	1,640
Total	(2/)	2,680	(2/)	1,820
Grand total:				
Reported consumption 3/	(2/)	4,540	(2/)	3,990
Apparent consumption 4/	(2/)	5,990	(2/)	5,420

W Withheld to avoid disclosing company proprietary data; included with "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 2000 PRICES OF ELEMENTAL IODINE AND SELECTED COMPOUNDS

(Dollars)

Elemental iodine/compounds	Value 1/	
	Per kilogram	Per pound
Calcium iodate, FCC drums, f.o.b. works	16.42	7.45
Calcium iodide, 50-kilogram drums, f.o.b. works	30.00	13.61
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
Sodium iodide, U.S.P., crystals, 5,000-pound lots, drums, freight-equalized	36.38	16.50

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. 258, no. 25, December 18, 2000, p. 23-28.

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/	1999		2000	
	Quantity	Value 3/	Quantity	Value 3/
Iodine, crude:				
Canada	4	33	--	--
Cayman Islands	--	--	18	234
Chile	3,490	54,800	3,450	49,100
China	--	--	5	47
Germany	3	52	--	--
Japan	1,480	25,300	1,220	18,600
Russia	109	1,880	87	1,260
Switzerland	36	540	--	--
Other 4/	21	365	7	68
Total	5,140	83,000	4,790	69,400
Iodide, potassium: 5/				
Canada	247	4,310	222	3,720
Chile	36	622	37	590
Japan	1	9	1	20
Other 6/	9	154	223	3,330
Total	293	5,090	483	7,660
Grand total	5,430	88,100	5,270	77,000

-- 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, freight (c.i.f.) valuation.
4/ Includes Georgia (1999), India, Mexico (2000), and the Netherlands (1999).
5/ Gross potassium iodide contains 76% crude iodine.
6/ Includes Denmark (1999), France (2000), Germany, India (1999), Israel, and the Netherlands (2000).

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)

	1999		2000	
Material type and country of origin 2/	Quantity	Value 3/	Quantity	Value 3/
Iodine, crude/resublimed:				
Canada	28	551	69	1,160
France	34	564	45	716
Germany	686	10,800	597	8,330
India	22	375	(4/)	5
Mexico	166	2,170	120	1,630
Netherlands	34	630	--	--
United Kingdom	--	--	68	978
Other 5/	138	2,340	109	1,780
Total	1,110	17,400	1,010	14,600
Iodide, potassium: 6/				
Australia	1	20	--	--
Mexico	7	120	8	141
Netherlands	2	50	3	49
Thailand	(4/)	9	--	--
Turkey	10	205	--	--
Other 7/	5	126	11	198
Total	25	530	22	388
Grand total	1,130	18,000	1,130	15,000

-- 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 Belgium, Columbia (2000), Costa Rica (1999), the Dominican Republic (2000), Denmark (2000), El Salvador (2000), Italy (1999), Japan, the Republic of Korea (1999), Norway (2000), Portugal (1999), Spain (1999), Taiwan (2000), Thailand, and Venezuela.
6/ Gross potassium iodide contains 76% crude iodine.
7/ Includes Denmark (1999), France (1999), Germany (2000), Indonesia (1999), Jamaica (1999), Malaysia (1999), Singapore (1999), Switzerland (2000), Taiwan (2000), the United Kingdom (1999), and Vietnam (1999).

Source: U.S. Census Bureau.

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

(Thousand kilograms)

Country	1996	1997	1998	1999	2000 e/
Azerbaijan e/	300	300	300	300	300
Chile 3/	5,514	7,154	9,722	9,317 r/	9,100
China e/	500	500	500	500	500
Indonesia e/	75	83	66	70	70
Japan	6,178	6,036	6,142	6,152 r/	6,100
Russia e/	250 r/	250 r/	280 r/	300 r/	300
Turkmenistan	35	87	90 e/	150 e/	150
United States	1,270	1,320	1,490	1,620	1,470 4/
Uzbekistan e/	--	--	1	2	2
Total	14,100 r/	15,700 r/	18,600 r/	18,400 r/	18,000

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 8, 2001.
3/ Includes iodine production reported by Servicio Nacional de Geologia y Minería.
4/ Reported figure.