Cadmium Markets and Trends
September 2005

During 2002 and 2003, cadmium consumption considerably exceeded cadmium supply. As a result, excess cadmium stocks were depleted and, in 2004 and 2005, cadmium supply and demand have now come back more into balance. However, continuing demand from the Chinese nickel-cadmium (NiCd) battery sector coupled with decreasing primary cadmium metal production and no excess stocks has resulted in upward price pressure in 2004 and 2005. Cadmium price levels have now recovered from their all time low levels of $0.25 per pound in mid-1998 to their historical average price over the past fifty years of about $2.00 per pound (not corrected for inflation).

At the same time, the regulatory situation regarding cadmium has really not been clarified but continues to drag on. While the European Union (EU) has issued its End-of-Life Vehicle Directive and its Restriction of Hazardous Substances in Electrical and Electronic Equipment Directive, both of which are aimed at eliminating cadmium in products, there are many exemptions to these Directives and many more are being applied for every day. The proposed revision to the European Union's Battery Directive has yet to be finalized, either with or without a NiCd battery ban, and already versions have exemptions. The EU's risk assessment on cadmium and cadmium oxide, along with its targeted risk assessment specifically on NiCd batteries, has not really produced the blanket condemnation of cadmium products that some regulators were hoping for. Thus, the regulatory emphasis for cadmium and cadmium products appears to be shifting from elimination and prohibition to proper management of any risk which might be present. For this reason, the previous predictions for the demise of the cadmium market have just not materialized.

Production

Primary cadmium metal production in 2004 and on into 2005 has continued to decrease from its highest levels in 1997 which roughly corresponds to the peak in worldwide NiCd battery production. Reductions in primary cadmium metal production have occurred mainly in Europe where many of the zinc/cadmium producers have shut down their cadmium refineries and now dispose of the cadmium-containing material from their zinc smelting process as hazardous waste. Asia and the Americas, on the other hand, have increased their cadmium primary production capacity from previous years, especially in Korea.

World primary production of cadmium metal, according to the World Bureau of Metal Statistics (WBMS), is summarized in Figure 1 and compared to primary metal consumption. Worldwide primary cadmium production continues to originate predominantly from Asia (China, Japan and Korea) and the Americas (Canada and Mexico) with only small production from Europe and Australia. African cadmium production which was always quite small has now virtually disappeared. Geographical primary cadmium metal production trends are shown in Figure 2 below.

It is expected that the production of primary cadmium metal will continue to increase in Asia, especially with the significant expansion of cadmium production in Korea in 2004. It is likewise expected that the primary cadmium metal production in Europe will continue to decline markedly, although secondary

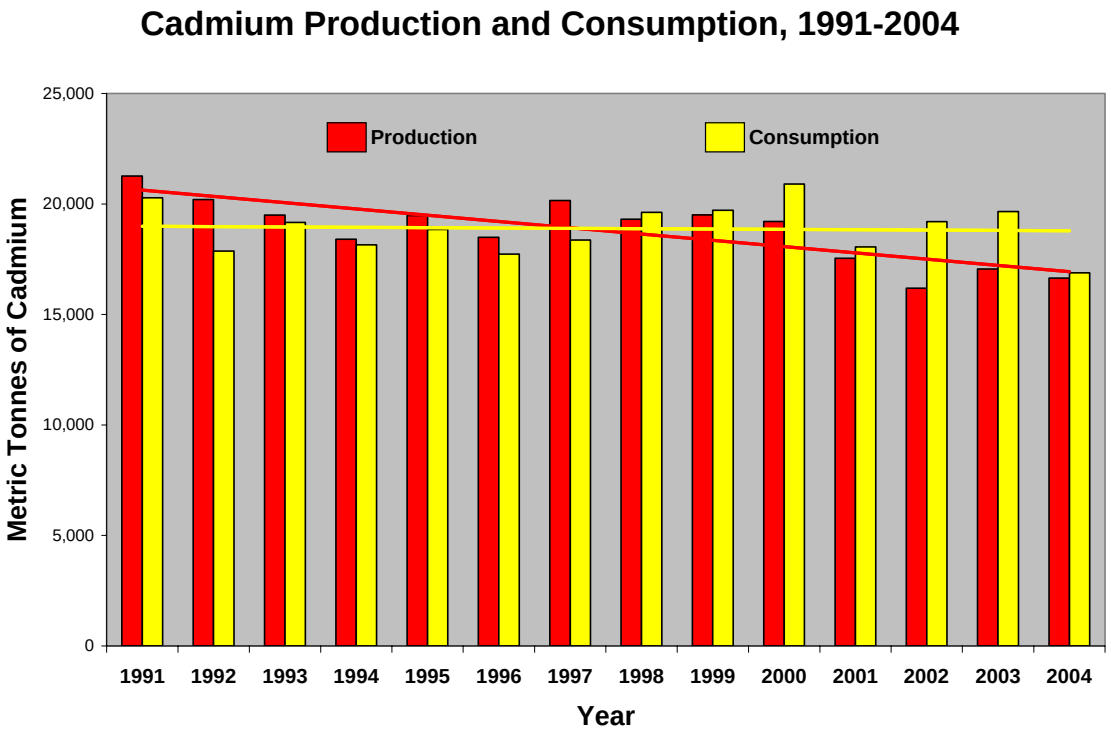

Figure 1. World Primary Production and Consumption of Cadmium Metal (WBMS)

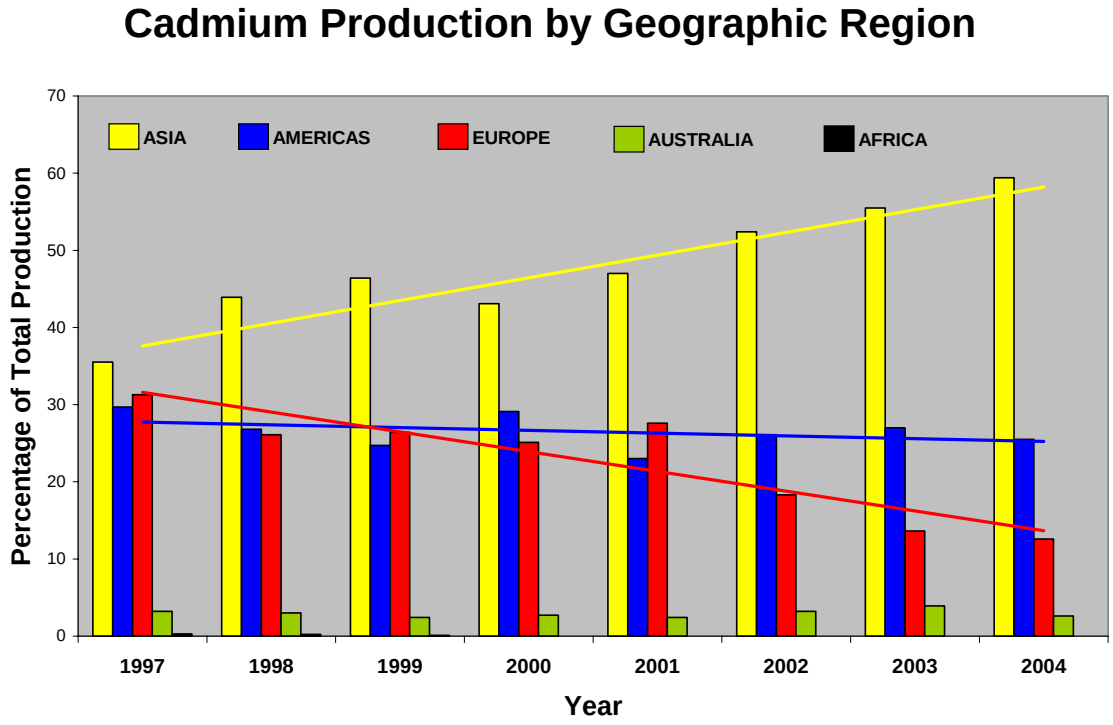

Figure 2. Geographical Trends in Primary Cadmium Metal Production

cadmium production from the recycling of NiCd batteries at S.N.A.M., SAFT and Accurec will most probably replace that primary cadmium production capacity in time. Primary cadmium metal production in the Americas is expected to remain relatively steady with Canada and Mexico increasing their production and the U.S.A. decreasing its primary production. However, once again, the decreased U.S.A. primary cadmium production will, in time, be replaced by secondary cadmium production from the recycling of NiCd batteries at INMETCO. The leading producing countries of primary cadmium metal are summarized in Figure 3 below.

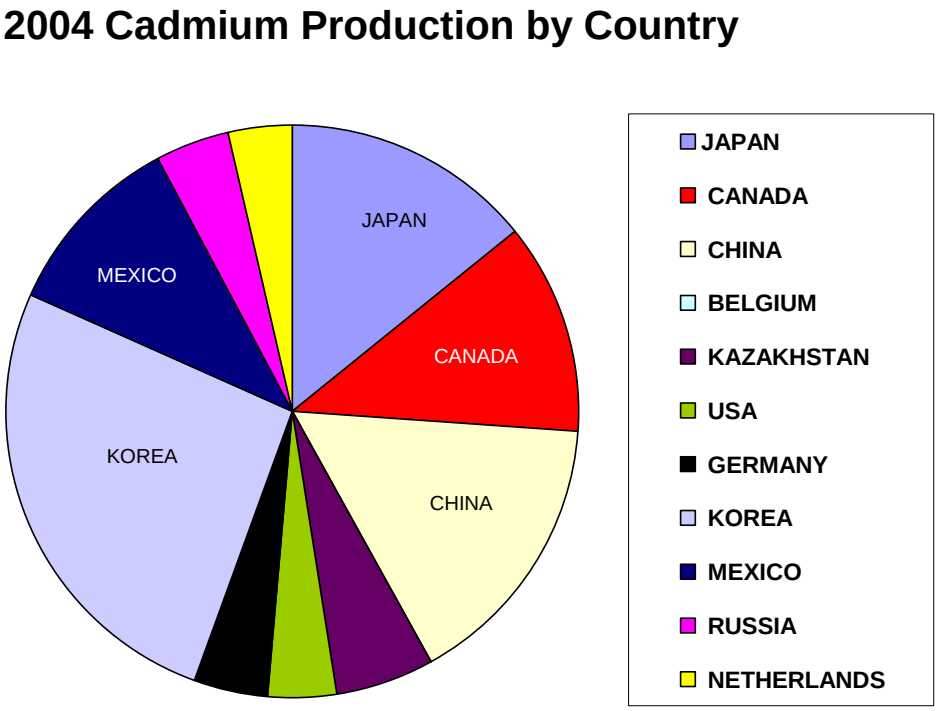

Figure 3. Leading producers of Primary Cadmium Metal in 2004 (WBMS)

The leading cadmium producers in Japan are Mitsui Mining & Smelting, Nippon Mining & Metals and Toho Zinc, all of whom are also involved in the recycling of NiCd batteries. The leading Chinese cadmium producers include Zhuzhou, Huludao, Shaoguan and Baiyin, while the main producer in Korea is Korea Zinc. The principal Mexican producers are Industrial Minera Mexico and Met-Mex Penoles, and the three Canadian producers include Falconbridge Limited, Hudson Bay and Teckcominco. Cadmium output in the United States comes from Zinifex's Clarksville smelter and INMETCO, a recycler of NiCd batteries.

Although primary cadmium supply has been decreasing, secondary cadmium supply has been increasing steadily over the past few years. There are three major industry programs in the world to organize and promote the collection and recycling of NiCd batteries – Rechargeable Battery Recycling Corporation (RBRC) in the United States and Canada, Battery Association of Japan (BAJ) in Japan, and RECHARGE (formerly CollectNiCad) in Europe. All three programs have exhibited consistent gains in total tonnages of NiCd batteries collected and recycled in their areas since their inception, and all of the recyclers associated with these programs have realized increased cadmium output from year to year. These recyclers include INMETCO in the United States, SAFT in Sweden, SNAM in France, Accurec in Germany, and Mitsui Mining & Smelting, Toho Zinc, Kansai Catalyst, Nippon Mining & Metals and Cobar Ltd in Japan. In total, these recyclers are estimated to produce about 3,500 mt of cadmium per year from the recycling of spent NiCd batteries. Thus, of the total supply of approximately 20,000 mt of cadmium, approximately 16,500 mt or 82.5% arises from primary cadmium production and the remaining 17.5% from secondary sources such as the recycling of NiCd batteries. Stocks and traders or government inventories have now

largely been depleted and are considered minimal and therefore did not significantly affect the cadmium market in 2004.

Consumption

Cadmium consumption has always been difficult to accurately establish. The figures generally reported are those for conversion of cadmium metal into cadmium oxide or cadmium sulfide, the direct use of cadmium metal for electroplating and coatings, and usage for production of cadmium-containing alloys and specialized chemical salts. The problem here is that cadmium oxide is often used as the starting material for other cadmium products, and that cadmium oxide is the primary material used in nickel-cadmium batteries. Thus, there is the danger that cadmium consumption figures may include double counting, for instance once in the conversion of metal to oxide and once again in the use of the oxide in NiCd batteries. It also must be noted that the consumption figures presented by WBMS, which are still the most consistent and reliable figures available, refer to consumption of primary cadmium and do not take into account consumption of secondary cadmium. It is well known that many NiCd battery manufacturers have arrangements with NiCd battery recyclers to supply a significant portion of their requirements, and indeed that the industrial NiCd battery manufacturer, SAFT, even has its own worldwide collection and recycling system and a recycling plant in Sweden. These reservations not withstanding, the world's apparent consumption of primary cadmium metal, according to WBMS, is summarized in Figure 1 and compared to production of primary cadmium metal.

The apparent consumption figures for primary cadmium metal shown in Figure 1 now reflect a much better balance between primary metal supply and demand. It is believed that total cadmium consumption demand is on the order of 20,000 to 21,000 metric tonnes and that the difference between total consumption and that supplied by primary production comes from secondary production or the recycling of nickel-cadmium batteries.

The world's leading cadmium consuming countries, according to WBMS, are summarized in Figure 4.

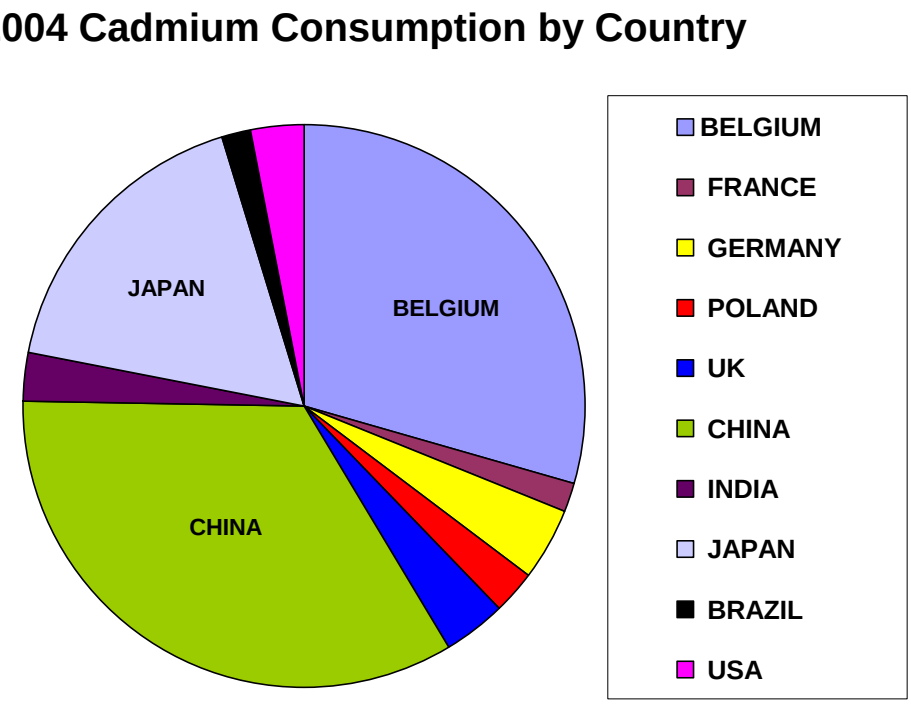

Figure 4. World's Leading Consumers of Refined Cadmium Metal (WBMS)

While the cadmium consumption statistics for some countries such as Japan are believed to be quite accurate, those for other nations, such as India, are only estimates and some have remained unchanged for years. The enormous cadmium consumption occurring in China has now been properly recognized and accurate consumption figures obtained. The consumption figures reported for Belgium reflect simply the conversion of cadmium metal into cadmium oxide as there are virtually no other cadmium consuming industries in Belgium. Most of the cadmium metal converted into cadmium oxide in Belgium is subsequently exported to China and Japan for the production of NiCd batteries.

China and Japan are, by far, the world's largest consumers of cadmium, and virtually all of that consumption is utilized for the production of nickel-cadmium batteries by manufacturers such as Sanyo in Japan, and BYD in China. Sanyo has now also established NiCd manufacturing facilities in both Japan and China. While cadmium consumption in Asia continues to climb, it is decreasing in some countries in Europe such as France but has remained steady in others such as the United Kingdom and Germany which have maintained a steady consumption level on the order of 600 mt per year over the past 5 years. What is interesting is that cadmium consumption is significant or increasing in some developing countries such as India and Brazil. European cadmium regulations appear to not have affected worldwide cadmium production or consumption but only driven those industries out of some countries in Europe to other areas of the world.

Applications

Cadmium and cadmium compounds are utilized in five major product areas which include NiCd batteries, pigments, stabilizers, coatings, and minor uses which include specialized alloys and electronic compounds. While definitive figures are not maintained for these application areas, the International Cadmium Association makes yearly estimates of cadmium consumption patterns for end-use categories which are summarized in Figure 5.

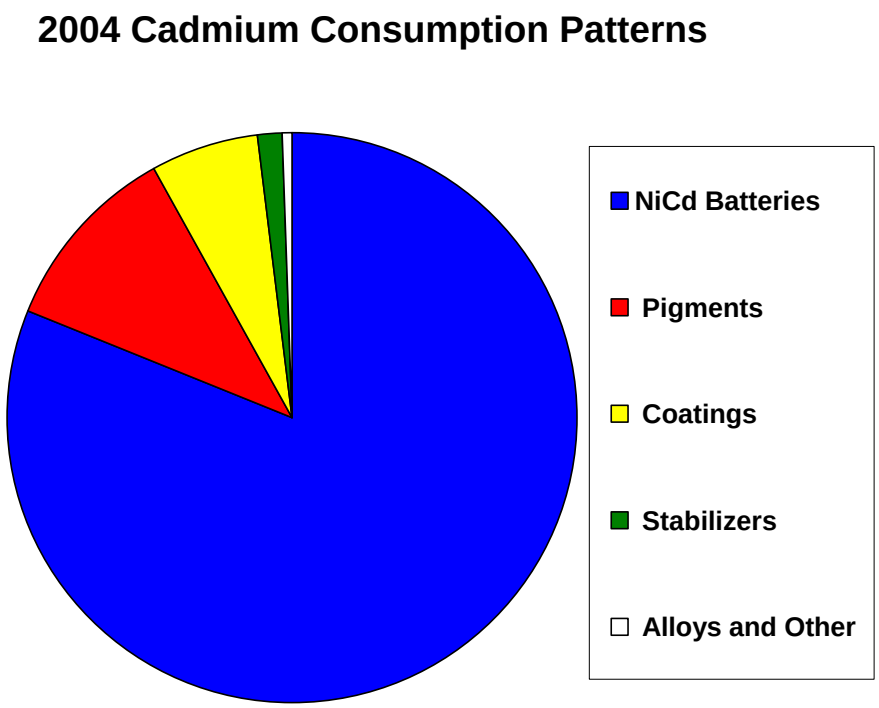

Figure 5. Estimated Worldwide Consumption Patterns for Cadmium in 2004 (ICdA)

The NiCd battery share of the cadmium market has continued to grow, while the stabilizers and minor use categories have continued to decrease. Cadmium sulfide-based pigments are used in plastics, glasses, enamels, ceramics and artists' colors. Cadmium coatings are utilized for the corrosion protection of iron and steel, aluminum and titanium, and have maintained steady usage throughout the world in spite of partial restrictions in the European Union. Cadmium-based products have been found to be irreplaceable in many pigment and coatings applications, and even the European Commission Directive 91/338/EEC on cadmium product restrictions grants exemptions for most of these irreplaceable applications. Restrictions generally do not exist on cadmium products outside of the European Union.

Cadmium-based stabilizers such as the barium sulfate-cadmium carboxylates (cadmium laurate or cadmium stearate) have been used extensively in the past to provide ultraviolet light and weathering resistance to polyvinylchloride (PVC). However, it has been found that other cadmium-free compounds such as calcium-zinc, barium-zinc and organo-tin stabilizers can be utilized equally well although they are not always as performance and cost-effective. Nevertheless, the ready availability of substitutes for many PVC applications has led to a general decrease in the usage of cadmium-barium stabilizers for PVC. Cadmium-stabilized PVC does continue to be utilized for some high-performance applications such as window frames.

Similarly, there have been many different types of cadmium-containing alloys used in the past for brazing and soldering applications which have now generally been replaced by cadmium-free compositions with equal performance. There are, however, several cadmium containing alloys for special-performance applications which have been found very difficult to replace. These include the silver – cadmium oxide electrical contact alloys used in switches and other applications where high electrical conductivity must be maintained along with arcing and electrical erosion resistance. Other unique alloys are the high-performance copper-cadmium alloys employed in heat conductivity or electrical conductivity applications where improved strength is imparted by the addition of cadmium with virtually no loss in either thermal or electrical conductivity.

However, the cadmium applications which continue to grow are all centered around the nickel-cadmium battery which has proven to be a very reliable, cost-effective battery for many applications in spite of the development of many other rechargeable battery chemistries and proposals for restrictions on NiCd batteries in the European Union. This market, at least from a cadmium consumption viewpoint, is made up of approximately 80% small consumer portable cells which are typically used in cordless power tools, cordless telephones and other communications devices, portable household appliances, emergency lighting, battery-powered toys and hobbies, and other portable electrical and electronic applications. The remaining 20% is consumed in the large industrial NiCd batteries used for railroad, aerospace, hybrid electric vehicle, standby power and telecommunications equipment applications. On a worldwide basis, both the portable and consumer NiCd battery markets continue to grow even though other battery chemistries have captured market share in some areas such as Western Europe. In countries like China, however, NiCd battery production is growing very rapidly, and the Chinese NiCd battery producer, BYD, is now the world's second largest portable NiCd battery producer behind Sanyo in Japan.

The small consumer portable NiCd batteries have continued to dominate the power tool, cordless telephone, emergency lighting and security, and portable household applications. Their on-going use is based partially on their excellent cost-effectiveness in these applications and their all-around combination of good battery performance characteristics. Other chemistries may exhibit superior performance for one or two parameters, but NiCds are consistently more highly-rated in a wide variety of characteristics. The worldwide markets for portable consumer NiCd batteries as well as those of other rechargeable battery chemistries have been described in detail by Hideo Takeshita of the Institute of Information Technology (IIT) Ltd. in Japan at the International Seminars & Exhibits on Primary & Secondary Batteries over the past few years. These market analyses are generally considered by the battery industry to be the best currently available. The trends in the uses of portable consumer NiCd batteries by application have been extracted from Takeshita's 2003, 2004 and 2005 presentations and are summarized in Figure 6 below.

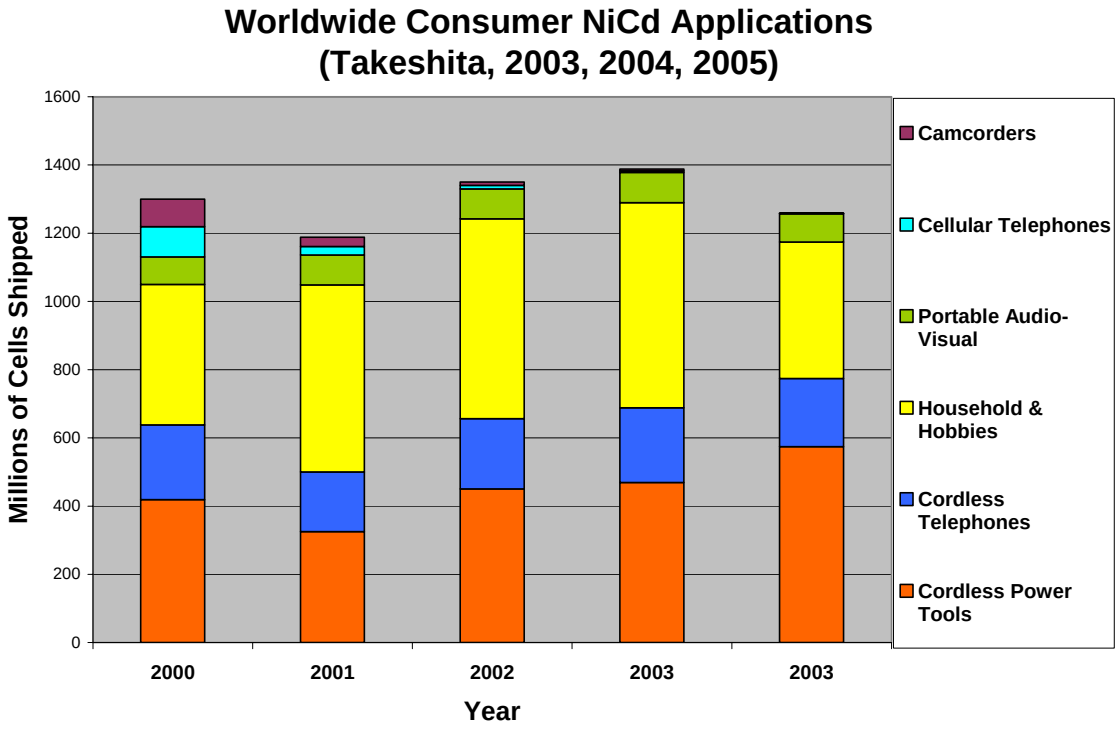

Figure 6. Worldwide Consumer Nickel-Cadmium Battery Shipments by Applications

On a worldwide basis, cordless power tools, cordless telephones, and cordless household appliances continue to be the mainstays of the nickel-cadmium battery industry. In the case of power tools, no other battery chemistry is able to achieve the rapid delivery of the high power necessary to operate power tools. In the case of cordless telephones and household appliances, it is the cost-effectiveness of NiCd batteries which make them so difficult to replace. In both cellular telephones and camcorders, and earlier in laptop computers, NiCd batteries were replaced first by nickel-metal hydride (NiMH) batteries and then by lithium-ion (Li-ion) batteries. In these latter applications, only the energy density of the battery is important in determining performance in the application, and the cost of the battery is very small compared to the cost of the device. Thus, the most expensive batteries (Li-ion for example) are used today in laptop computers to obtain the highest energy density and longest running time, regardless of the battery cost.

There is little doubt that the future of the nickel-cadmium battery market rests with its use in cordless power tools. The power tool market has been growing at very rapid rates in recent years and, in spite of claims that NiMH batteries will replace NiCd batteries in power tools, the power manufacturers who have evaluated both chemistries indicate that NiMH systems just do not have the characteristics necessary for use in power tools. On the other hand, cordless power tools have gradually been shifting to higher and higher energy outputs. Whereas most early cordless power tools operated at 9.6 volts or less, today's cordless power tools having been rapidly shifting to the 12 volt, 14.4 volt, 18 volt and now even the 24 volt models. Since each individual NiCd cell operates at 1.2 volts, high voltage power tools require power packs with many NiCd cells. Lithium ion (Li-ion) batteries, on the other hand, operate at 3.6 volts, and thus require far fewer cells to obtain the high voltage power packs. Li-ion batteries still have many disadvantages compared to NiCd batteries such as cost, cycle life, temperature operating range, and susceptibility to overcharge, but nonetheless their light weight and high energy make them interesting challengers to NiCd batteries in cordless power tools in the future.

Other future applications for NiCd batteries could include hybrid electric vehicles, telecommunications, and remote area power systems. A 1998 estimate by SAFT America placed the potential cadmium market in NiCd batteries in telecommunications alone at 2,000 mt per year, and that market is slowly but steadily

developing. As more advanced battery systems are developed and displace NiCd batteries from some of their current applications, it is expected that NiCd batteries will displace lower performance batteries such as the lead acid and primary alkaline manganese chemistries in some of their applications. NiCd batteries are also promising for hybrid electric vehicles (HEVs) and will capture a modest share of that market. Even though the American and Japanese manufacturers appear to favor either NiMH or Li-ion batteries for HEVs, the Europeans curiously enough appear to have largely adopted NiCd batteries for their electric vehicles. A recent market report indicated that approximately 80% of the electric vehicle batteries in Europe were in fact NiCds. Estimates of the hybrid electric vehicle market predict that there will be at least two million HEVs worldwide by 2010. Given the popularity of HEVs in the United States, this estimate may be conservative. Even if NiCds capture only 10% of that market, it would represent a significant new use for NiCd batteries. The attractive feature of the use of NiCds in HEVs is that they would be readily collected and recycled in this application, and therefore would pose little environmental concern.

Included in the minor uses category are the cadmium sulfide and cadmium telluride (CdTe) based electronic devices which are used in many functions in today's electrical and electronic equipment. One of the most promising from the cadmium industry's perspective is the use of CdTe solar cells to convert sunlight into electricity and the use of NiCd batteries to store that electrical energy for remote area power systems (RAPS). One analysis suggested that the additional cadmium consumption from the CdTe/RAPS application could eventually be as high as 5,000 mt per annum, although current usage is only a fraction of that level. First Solar LLP in the United States has developed cost effective and high speed production techniques for manufacturing CdTe solar cells along with technology for recycling their solar cells after use. Many have predicted that these developments could substantially advance the introduction of solar energy on a larger scale around the world.

In addition, many other electronic cadmium compounds exhibit semi-conducting properties which make them valuable for gates, switches, sensors, detectors and relays. These applications normally require high purity and therefore higher cost cadmium. The volume of cadmium consumed in these applications is small, but could increase in the future. However, the European Commission Directive on the Restriction of Hazardous Substances in Electrical and Electronic Equipment (ROHS) mandates the complete elimination of cadmium in electronic equipment. However, now there are several exemptions such as cadmium coatings to the ROHS Directive and more have been proposed.

Future applications for cadmium should be recyclable to the greatest extent possible. Today, batteries, coatings, alloys and CdTe solar cells are all recyclable. Both the NiCd battery industry and CdTe solar cell industry have undertaken product stewardship programs to ensure that their cadmium-containing spent products and production wastes are collected and recycled. Recycling of coatings and alloys has generally not been justified economically in recent years in view of the low price of cadmium and/or the low cadmium content in the waste material being recycled. With the current price of cadmium moving up past the $2 per pound level, the economics for recycling these products may become more justifiable. Technologically it is possible to recycle both cadmium coatings and alloys, and both have been recycled in the past when economics were more favorable or when the recycling of very valuable metals was simultaneously involved such as in the recycling of silver-cadmium oxide electrical contact alloys.

From a public perception point-of-view, it is also necessary to emphasize that many of the applications for cadmium are sustainable, and need not be viewed as detrimental to human health and the environment as they have been in the past. Environmentally-positive applications such as hybrid electric vehicles, solar cells and long-lived, recyclable and rechargeable NiCd batteries to replace non-rechargeable and non-recyclable batteries are environmentally beneficial, and their continued use should be encouraged, not prohibited. The cadmium industry has always argued that the use of cadmium in products is environmentally more beneficial than disposing of the cadmium extracted from nonferrous metals smelting and refining as a hazardous waste.

Prices

At the end of 2000, published *Metal Bulletin* average prices for both 99.95 and 99.99 grade cadmium metal were at close to their lowest historical levels, about $0.20 per pound. Prices increased in the spring and

summer of 2001, but only to the $0.50 to $0.60 per pound level and then fell back again. During the fall and early winter of 2003, prices once again rose, this time to the $0.80 per pound level and then retreated once again in the winter and early spring of 2004. During much of 2004, cadmium prices remained in the $0.60 to $0.80 per pound level. Finally, in February 2005, with continued demand from the Chinese NiCd battery industry and declining primary cadmium production, prices began to rise in February 2005 and have been rising ever since. The very rapid rise occurred in May 2005 and, as of August 2005, the *Metal Bulletin* published price for the high end of the range for 99.99 grade cadmium stood at $2.225 per pound. The price history for the upper range of 99.99 purity grade cadmium metal, as published by *Metal Bulletin*, is summarized in Figure 7 below.

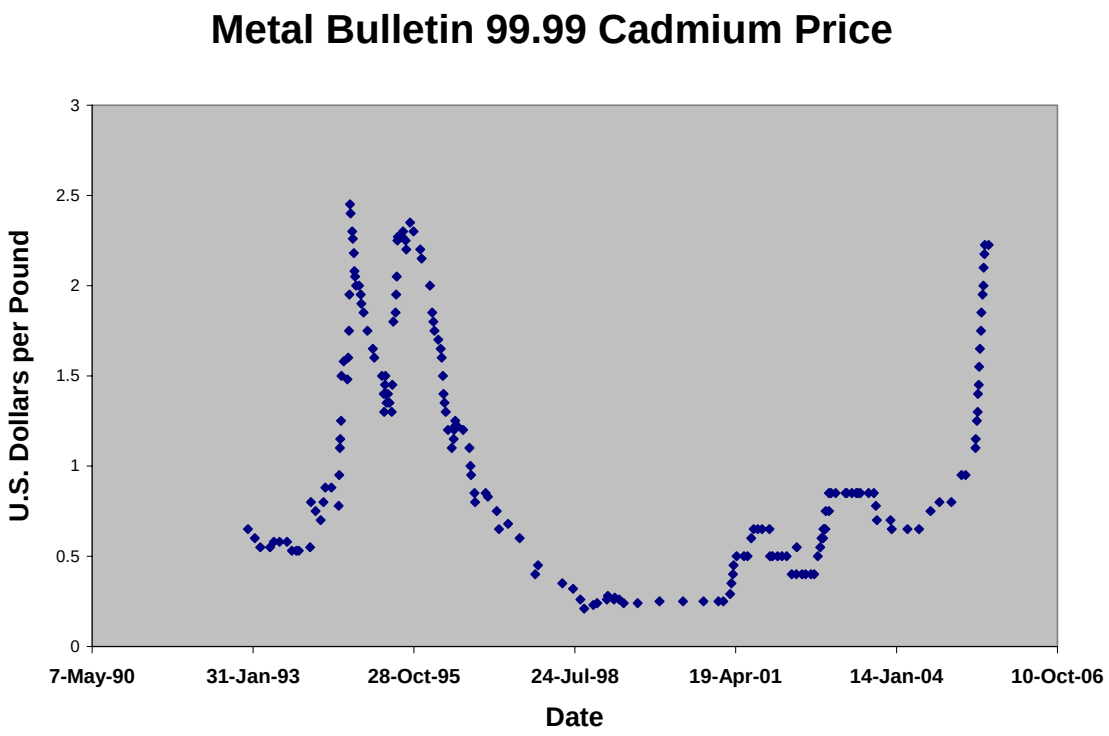

Figure 7. Metal Bulletin Price History for Upper Range for 99.99 Purity Cadmium Metal

Current cadmium prices are now above the all time historical average price for cadmium at $2.00 per pound and are generally above the production or disposal costs of cadmium for most primary zinc producers. However, some large primary cadmium producers have permanently shut down their cadmium production capacity and others may be fearful that the current higher prices for cadmium may only be short-lived. Thus, it appears unlikely that primary cadmium production will ever return to its former levels and that secondary or recycled cadmium production will be necessary to meet continuing demand. Future cadmium price will most likely continue to depend upon the on-going shortfall between cadmium supply and demand and whether sustained demand will continue to be realized from Chinese NiCd battery production and, perhaps in the future, from Korean, Indian or even Brazilian usage.

Future Outlook

The cadmium market today is considerably more positive than it was a year ago. Primary cadmium supply is still decreasing, but secondary cadmium supply is increasing to fill in the gap between supply and demand. Excess cadmium stocks appear to have been depleted. Cadmium prices are now at or above the historical average prices of $2 per pound (not corrected for inflation) over the past 50 years and are

continuing to climb. Cadmium applications are increasingly dominated by the nickel-cadmium battery, particularly the small portable consumer cells used in power tools, emergency lighting and security, household appliances, cordless telephones and other communications devices. A modest but steady use continues in cadmium pigments and coatings for certain critical applications where viable substitutes have not been established. Cadmium stabilizers and the cadmium-containing brazing and soldering alloys are being replaced and eventually will disappear, but a small usage will probably continue for cadmium-containing specialty alloys and cadmium-based electronic compounds in solar cells and other electronic applications.

The continued strength of the NiCd battery market has resulted from the strength of Chinese NiCd battery production which is due in large part to their advantageous labor, production, overhead and profit costs. The impressive fact is that this increased Chinese production has not resulted in a significant decrease in Japanese NiCd production and must partially be considered new consumption, both for the growing domestic Chinese market and for their export market. In the future, it is also quite possible that strong growth could occur in other Third World markets such as India, Russia and Brazil, although perhaps not as strong or as rapid as the Chinese explosion of the past 5 years. Cadmium consumption figures for 2004 show both Brazilian and Indian demand to be strong and significant.

However, these positive factors for the NiCd battery and cadmium markets must be tempered with the concerns over the human health and environmental issues surrounding cadmium, and the steps that the Environment Directorate of the European Commission, along with certain Nordic countries, have taken to restrict the use of cadmium-containing products. It is believed that the risk has been greatly exaggerated and, indeed, the final risk assessments on cadmium/cadmium oxide and on NiCd batteries developed by the European Commission generally show that the levels of risk associated with the manufacture, use and disposal of these batteries are not unacceptable. Any risks shown to be present with regard to cadmium products can be managed and, in the case of NiCd batteries, largely be mitigated by the promotion of battery collection and recycling such as those established by the Battery Association of Japan (BAJ) in Japan and the Rechargeable Battery Recycling Corporation (RBRC) in the United States and Canada, and advocated by RECHARGE in Europe. Eventually these programs must be worldwide, and already several countries in Asia and South America have explored the possibilities of establishing labeling, collection and recycling programs for NiCd batteries. Many jurisdictions, indeed, have already mandated the collection and recycling of all battery chemistries, recognizing that the degree of recycling may be improved by collecting all chemistries and that the degree of recycling achieved is a far more important environmental impact factor than the specific battery chemistry.

Cadmium will continue to be produced as a by-product as long as zinc, lead and copper are produced. The real questions are whether primary producers will largely elect to curtail cadmium production as many have in the last three years because of environmental regulations and poor economics and dispose of cadmium as hazardous waste, or whether cadmium will continue to be refined and utilized as a valuable by-product and then recycled so as to minimize any human health or environmental impact. The current increase in cadmium prices would favor the latter option, but some primary producers have already closed down their cadmium production facility while others are uncertain about future cadmium prices. Secondary cadmium production, mainly from the recycling of nickel-cadmium batteries, appears to offer the best prospects for both maintaining a stable cadmium price scenario and for minimizing and best managing any environmental risks from cadmium products.

Hugh Morrow
September 2005