CADMIUM

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In spite of decreased primary production, increased consumption, and only modest increases in recycling, cadmium prices decreased in 2003 when most traditional supply-demand dynamics would have predicted increased cadmium prices. It is speculated that the reasons behind this behaviour lie in an increasing amount of raw material being processed in China for the Chinese NiCd battery industry, and possibly to an increasing number of cadmium tolling arrangements between NiCd battery recyclers and NiCd battery manufacturers.

In addition, more uncertainty has now been introduced into the final status of the European Union Battery Directive. In 2002 and 2003, the European Commission proposed a Battery Directive, which did not call for a ban on NiCd batteries but rather an ambitious collection and recycling programme for NiCd batteries. This proposal has now been sent to the European Parliament, which has reintroduced the concept of a NiCd battery ban as well as a ban on small sealed lead acid batteries. Until the outcome of the EU's proposed Battery Directive has been resolved, there will continue to be uncertainty and weakness in cadmium prices. As it always has been, the cadmium market is a very volatile and uncertain one, and even minor developments can result in major price movements.

Production

Primary cadmium metal production in 2003 continued at the reduced levels first seen in 2002 when cadmium production cutbacks were initiated by many zinc producers in Europe. Umicore, Outokumpu, Britannia, Metaleurop, Asturiana and Samim, all of whom were previously cadmium producers in Europe, have now shut down operations or have curtailed cadmium production significantly. Only Budel in the Netherlands continues to be a significant cadmium producer in Europe.

World primary production of cadmium metal, according to the World Bureau of Metal Statistics (WBMS), is summarised in Table I.

Worldwide primary cadmium production continues to originate predominantly from Asia, the Americas and Europe. Australian production had declined significantly from its levels in the early 1990s but bounced back in 2003, and African production today is essentially non-existent. The interesting trend is that, while primary production from Europe has been declining significantly, cadmium output from Asia has increased dramatically. Primary cadmium production from the Americas has remained steady at about one quarter of total worldwide production. Trends in geographical primary cadmium metal production are summarised in Table 2.

Amongst the Asian nations, China, Japan and Korea are the leading producers. In the Americas, Canada and Mexico are now the most significant producers, and in Europe, only the Netherlands continues to be a significant cadmium primary producer. The WBMS figures shown in Table 3 for Germany are believed to be too high. France is a significant producer of secondary or recycled cadmium because of its NiCd battery recycling operations at SNAM. Production from the leading primary cadmium metal-producing countries according to WBMS is shown in Table 3.

The leading cadmium producers in Japan are Mitsui Mining & Smelting and Toho Zinc, both of whom are also involved in the recycling of NiCd batteries. The leading Chinese cadmium producers include Zhushou, Huludao, Shaoguan and Baiyin, and the main producer in South Korea is Korea Zinc. The principal Mexican producers are Industrial Minera Mexico and Met-Mex Penoles, and the four Canadian producers include Noranda, Falconbridge, Hudson Bay and Teck Cominco. Cadmium output in the US comes from Pasminco Zinc USA and INMETCO, a recycler of NiCd batteries.

As noted above, the single largest factor causing decreased primary cadmium metal production in 2002 and 2003 was the cessation of cadmium production by Umicore in Belgium. However, other cadmium production has also shut down in Europe during the last two years. Asturiana de Zinc in Spain, now part of Xstrata, had stopped producing cadmium several years ago, but now has acquired the Nordenham zinc smelter in Germany from Metaleurop, and it is reported that a small amount of cadmium is being produced there. MIM's Britannia Zinc in the UK and Glencore's Portovesme refinery in Italy have also both ceased cadmium production. While European cadmium production has been curtailed, Japanese, Chinese, Korean, Canadian and Mexican primary cadmium production all increased in 2003 over 2002. It has been speculated that, because of the regulatory situation in Europe regarding cadmium, European zinc producers are now simply shipping the cadmium extracted from their zinc ore concentrates to China for direct refining into pure cadmium metal for NiCd battery production rather than refining it themselves.

Although primary cadmium supply has been decreasing, secondary cadmium supply has been increasing steadily over the past few years. There are three major industry collection and recycling programmes in the world – the Rechargeable Battery Recycling Corp (RBRC) programme in the US and Canada, the Battery Association of Japan (BAJ) programme in Japan, and the CollectNiCad (CNC) programme in Europe. All three programmes have exhibited consistent gains in total tonnages of NiCd batteries collected and recycled since their inception, and all of the recyclers associated with these programmes have realised increased cadmium output from year to year. These recyclers include: INMETCO in the US, 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 t/y of cadmium from the recycling of spent NiCd batteries. Thus, of the total supply of approximately 20,000 t of cadmium, approximately 16,500 t or 82.5% arises from primary cadmium production and the remaining 17.5% from secondary sources such

as the recycling of NiCd batteries. Neither stocks and traders nor government inventories have changed significantly in the past few years and were not really factors in the cadmium market in 2003.

Consumption

Cadmium consumption is very difficult to establish accurately. The figures generally reported are those for conversion of cadmium metal into cadmium oxide or cadmium sulphide, the direct use of cadmium metal for electroplating and coatings, and usage for production of cadmium-containing alloys and specialised 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 summarised in Table 4.

These apparent consumption figures indicate that WBMS has made revisions from its 2002 figures to correct the double counting problem previously noted and has gathered more accurate information on the real cadmium consumption in the Chinese NiCd battery industry. Comparison of the consumption data in Table 4 with total supply indicates that apparent demand exceeds primary cadmium supply by about 3,500 t, which is now generally assumed to be filled by secondary or recycled cadmium.

The world's leading cadmium-consuming countries, according to WBMS, are summarised in Table 5. While the cadmium consumption statistics for some countries such as Japan are believed to be quite accurate, those for other nations are only estimates and some have remained unchanged for years. For example, it has only been recently that the enormous cadmium consumption occurring in China has been recognised and more accurate consumption figures obtained. It also must be kept in mind that the consumption figures for Belgium reflect simply the conversion of cadmium metal into cadmium oxide as there are virtually no other cadmium-consuming industries in Belgium of any magnitude. 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 utilised in the production of NiCd batteries by manufacturers such as Sanyo and Panasonic in Japan, and BYD and GP

in China. Sanyo and Matsushita/Panasonic have now also established NiCd manufacturing facilities in both Japan and China. While cadmium consumption in Asia continues to climb, it is decreasing in Europe, with the exception of the UK which has maintained a steady consumption level of roughly 600 t/y over the past five years. What is interesting is that cadmium consumption is now significant or increasing in some developing countries such as India and Brazil. European cadmium regulations appear not to have affected worldwide cadmium production or consumption but only to have driven industries out of Europe to other areas of the world.

Applications

Cadmium and cadmium compounds are utilised in five major product areas which include NiCd batteries, pigments, stabilisers, coatings, and minor uses which include specialised 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 summarised in Table 6.

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

Cadmium-based stabilisers such as the barium sulphate-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 stabilisers can be utilised equally well although they are not always as effective as regards performance and cost. Nevertheless, the ready availability of substitutes for many PVC applications has led to a general decrease in the usage of cadmium-barium stabilisers for PVC. Cadmium-stabilised PVC does continue to be utilised 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 centred 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 EU. This market, at least from a cadmium consumption viewpoint, is made up of approximately 80% small consumer-portable cells, used typically 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 vehicles, 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-round combination of good battery performance characteristics. Other chemistries may exhibit superior performance in one or two characteristics, but NiCds are consistently more highly-rated in a wide variety of parameters. The worldwide markets for NiCd batteries, as well as those of other rechargeable battery chemistries, were described in detail by Hideo Takeshita of the Institute of Information Technology Ltd in Japan at the 20th. International Seminar & Exhibition on Primary & Secondary Batteries in March 2003 in Deerfield Beach, Florida. The trends in the uses of NiCd batteries by application were extracted from that presentation and are summarised in Table 7.

On a worldwide basis, cordless power tools, cordless telephones, and cordless household appliances continue to be the mainstays of the NiCd 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 that makes 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.

Future applications for NiCd batteries 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 t/y, 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. A recent estimate of the hybrid electric vehicle market predicted that there would be two million HEVs by 2010. Even if NiCds captured 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 sulphide 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 t/y, although current usage is only a fraction of that level. 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, another new EC Directive on the Restriction of Hazardous Substances in Electrical and Electronic Equipment (ROHS) mandates the complete elimination of cadmium in electronic equipment, with only a few exemptions such as cadmium coatings. This EC Directive could produce future negative effects on the use of cadmium speciality alloys and semiconductors unless additional exemptions are granted for critical applications where other materials are inadequate or not cost-effective.

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 programmes 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. However, technologically it is possible to recycle both of these cadmium products, and both have been recycled in the past when economics were more favourable, or when the

recycling of very valuable metals was simultaneously involved such as in the recycling of silver-cadmium oxide electrical contact alloys. In addition, efforts are under way in the cadmium pigments industry to recycle cadmium-pigmented engineering plastics, their major use.

From a public perception, it is also necessary to emphasise 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 banned.

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 US$0.20/lb. In March and April 2001, the price for high-purity 99.99-grade cadmium jumped up to about US$0.50/lb, but the average price for 99.95 grade remained at US$0.30/lb for most of 2001. Later in 2001, prices for 99.99 NiCd battery grade material increased again, to above US$0.60/lb, but then fell back down to the US$0.30/lb level for the first half of 2002. Beginning in August and September 2002, prices, first for 99.99 grade and then for 99.95 grade, began to increase sharply. By the end of 2002, the price range for 99.99 grade stood at US$0.70-.85/lb, and that for 99.95 grade was US$0.60-0.70/lb. During most of 2003, the price for 99.99-grade cadmium remained in the US$0.70-0.85/lb range. However, late in the year, and in spite of the apparently significant shortfall in supply compared with demand, the cadmium price fell sharply in September 2003 and then again in December to finish the year at US$0.55-0.65/lb for 99.99% purity cadmium.

Although these prices were certainly an improvement from the all-time historical lows of US$0.20/lb seen in 2000, they are still considerably below the average cadmium price over the past 50 years of approximately US$2.00/lb and even below the level of US$1.00/lb, which many producers consider as roughly the production cost for cadmium. Thus, even though the cadmium market and cadmium prices appeared to be improving in late 2002 and much of 2003, they have been depressed so low and for so long that considerable and sustained improvements will be necessary to restore industry health. The supply-demand imbalance of the past few years should have tended to improve cadmium prices and perhaps encourage those producers who had abandoned cadmium production to resume it, but it did not. Increased recycling of NiCd batteries and direct processing of partially-processed material in China appear to have been utilised to avoid the volatility of the cadmium market in the late 1980s, and cadmium prices have remained both low and stable.

Future outlook

The cadmium market today remains in a great state of flux and uncertainty. Primary cadmium supply is decreasing, but secondary cadmium supply is increasing. Excess cadmium stocks appear to have diminished or been

depleted. In spite of an apparent supply/demand imbalance, cadmium prices are still well below the historical average prices of US$2/lb over the past 50 years. 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 stabilisers 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, and is due in large part to their advantageous labour, production, overhead and profit costs. The impressive fact is that this increased Chinese production has not resulted in a decrease in Japanese NiCd production and must 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 five years. Cadmium consumption figures for 2003 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 EC Environment Directorate, along with certain Nordic countries, have taken to restrict the use of NiCd batteries. 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 EC 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 NiCd batteries can largely be mitigated by the development of NiCd battery collection and recycling programmes, such as those established by the BAJ in Japan, the RBRC in the US and Canada, and CNC in Europe. Eventually, these programmes must be worldwide, and already several countries in Asia and South America have explored the possibilities of establishing labelling, collection and recycling programmes for NiCd batteries. Many jurisdictions, indeed, have already mandated the collection and recycling of all battery chemistries, recognising that a degree of recycling is probably a far more important environmental impact factor than the actual 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 elect to curtail cadmium production as many have in the past two years because of environmental regulations and poor economics, or whether cadmium will continue to be refined and utilised as a valuable by-product and then recycled so as to minimise any human health or environmental impact.

Industry would prefer the latter, but at this transition point must also examine all options.

Table 1: World primary production of refined cadmium metal (t)

Year	Production
1992	20,197
1993	19,497
1994	18,411
1995	19,478
1996	18,489
1997	20,153
1998	19,312
1999	19,539
2000	19,363
2001	17,747
2002	16,211
2003	16,487

Table 2: Geographical trends in primary cadmium production (% share by region)

Year	Asia	Americas	Europe	Australia
1995	36.0	27.4	31.5	4.6
1996	37.2	29.7	29.2	3.5
1997	35.5	29.7	31.3	3.2
1998	43.9	26.8	26.0	3.0
1999	46.1	25.2	26.1	2.3
2000	43.5	29.4	24.1	2.7
2001	47.6	23.5	26.8	2.1
2002	46.6	25.9	25.2	2.3
2003	55.8	26.6	13.2	4.4

Table 3: Leading producers of refined cadmium metal (t)

Country	1999	2000	2001	2002	2003
Japan	2,586	2,439	2,467	2,426	2,553
China	2,154	2,368	2,368	2,441	2,441
South Korea	1,995	2,114	2,083	2,031	2,298
Mexico	1,275	1,268	1,421	1,399	1,598
Canada	1,911	1,941	1,429	1,706	1,744
Russia	900	780	620	650	650
US	1,190	1,890	680	700	700
Kasakhstan	1,061	257	170	479	790
Netherlands	731	628	455	485	468
Germany	703	458	539	422	422
Belgium	1,235	1,148	1,236	117	0

Table 4: Worldwide apparent consumption of cadmium metal (t)

Year	t
1991	20,283
1992	17,870
1993	19,165
1994	18,149
1995	18,847
1996	17,726
1997	18,370
1998	19,623
1999	19,712
2000	20,907
2001	18,193
2002	19226
2003	20,067

Table 5: Leading cadmium-consuming countries

Apparent Cadmium Consumption (Mt)					
Country	**1999**	**2000**	**2001**	**2002**	**2003**
Japan	5,851	6,810	4,650	5,372	6,260
China	2,866	4,854	5,268	5,407	5,407
Belgium	4,065	3,559	4,426	4,755	4,301
US	1,850	2,010	679	560	671
UK	631	585	584	589	590
India	446	446	446	446	446
Germany	658	412	593	499	435
Brazil	12	12	15	37	269
France	1,800	1,000	306	241	241
South Korea	380	380	200	79	124

Table 6: Worldwide cadmium consumption patterns by market segment (% of total consumption)

	1997	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
Batteries	70	72	73	75	77	78	80
Pigments	13	13	13	12	12	12	11
Coatings	8	8	8	8	8	8	7
Stabilisers	7	6	5	4	2	1.5	1.5
Alloys and Compounds	2	1	1	1	<1	0.5	0.5

Table 7: Worldwide NiCd battery shipments by application (Takeshita, 2003) (millions of cells)

Application Sector	2000	2001	2002	2003
Cordless Power Tools	419	325	450	469
Cordless Telephones	219	175	206	219
Household & Hobbies	412	548	586	602
Portable Audio-Visual	81	88	88	88
Cellular Telephones	88	25	10	5
Camcorders	81	27	10	5
TOTAL	**1,300**	**1,188**	**1,350**	**1,388**