CADMIUM

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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 US$0.25/lb in mid-1998 to their historical average price over the past fifty years of over US$2.00/lb.

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 EU’s Battery Directive has yet to be finalised, 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 materialised.

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 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 summarised in Table I.

Table I: World primary production of refined cadmium metal

Year	Production (t)
1992	20,197
1993	19,497
1994	18,411
1995	19,478
1996	18,489
1997	20,153
1998	19,312
1999	19,509
2000	19,214
2001	17,547
2002	16,195
2003	17,062
2004	16,649

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 Table II below.

Table II: Geographical trends in primary cadmium metal production

	Percent of total world primary cadmium metal Production			
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	26.1	3.0
1999	46.4	24.7	26.4	2.4
2000	43.1	29.1	25.1	2.7
2001	47.0	23.0	27.6	2.4
2002	52.4	26.1	18.3	3.2
2003	55.5	27.0	13.6	3.9
2004	59.4	25.5	12.6	2.6

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 primary cadmium metal production in Europe will continue to decline markedly, although secondary cadmium production from the recycling of NiCd batteries at SNAM, 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 US decreasing its primary production. However, once again, the decreased US 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 Table III below.

Table III: Leading producers of primary cadmium metal, 2000 – 2004

		Primary cadmium metal production (t)			
Country	**2000**	**2001**	**2002**	**2003**	**2004**
Japan	2,439	2,467	2,589	2,496	2,209
China	2,368	2,368	2,368	2,705	2,441
Korea	2,114	2,083	2,041	2,379	4,065
Mexico	1,268	1,421	1,464	1,606	1,614
Canada	1,941	1,429	1,429	1,759	1,833
United States	1,890	680	680	700	600
Russia	925	925	925	650	650
Kazakhstan	257	170	615	795	864
Netherlands	628	455	473	495	572
Germany	458	539	394	640	640
Belgium	1,148	1,236	200	0	0

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, and the main producer in Korea is Korea Zinc. The principal Mexican producers are Industrial Minera Mexico and Met-Mex Penoles, and the leading Canadian producers include Noranda/Falconbridge, Hudson Bay Mining & Smelting and Teck Cominco. Cadmium output in the US 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 collection and recycling programmes in the world – the Rechargeable Battery Recycling Corporation (RBRC) programme in the US and Canada, the Battery Association of Japan (BAJ) programme in Japan, and the

RECHARGE (formerly CollectNiCad) 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/y 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. 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 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 NiCd 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 IV.

Table IV: Worldwide apparent consumption of primary cadmium metal

Year	Apparent consumption (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	18,062
2002	19,205
2003	19,662
2004	16,888

The apparent consumption figures for primary cadmium metal shown in Table IV 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 t to 21,000 t and that the difference between total consumption and that supplied by primary production comes from secondary production or the recycling of NiCd batteries.

The world's leading cadmium-consuming countries, according to WBMS, are summarised in Table V. 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 recognised 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.

Table V: World's leading consumers of refined cadmium metal

	Apparent cadmium consumption (t)				
Country	**2000**	**2001**	**2002**	**2003**	**2004**
Japan	6,810	4,650	5,372	6,062	2,764
China	4,854	5,268	5,372	6,062	5,407
Belgium	3,559	4,426	4,755	3,643	4,739
United States	1,850	2,010	560	530	500
United Kingdom	585	584	589	591	592
India	446	446	446	446	446
Germany	412	593	499	651	688
Brazil	12	15	37	240	276
France	1,000	306	241	241	241
South Korea	380	200	94	100	100

China and Japan are, by far, the world's largest consumers of cadmium, and virtually all of that consumption is utilised for 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. Although 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 UK and Germany, which have maintained a steady consumption level of the order of 600 t/y over the past five 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 not to 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 utilised in five major product areas, which include NiCd batteries, pigments, stabilisers, coatings, and minor uses such as specialised alloys and electronic compounds. While definitive figures are not maintained for these application areas, the International Cadmium Association (ICA) makes yearly estimates of cadmium consumption patterns for end-use categories which are summarised in Table VI.

Table VI: Estimated worldwide cadmium consumption patterns

Market	Percent of total cadmium consumption								
Segment	1996	1997	1998	1999	2000	2001	2002	2003	2004
Batteries	69	70	72	73	75	77	78	80	81
Pigments	13	13	13	13	12	12	12	11	11
Coatings	8	8	8	8	8	8	8	7	6
Stabilisers	8	7	6	5	4	4	1.5	1.5	1.5
Minor uses	2	2	1	1	1	<1	0.5	0.5	0.5

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 generally 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 in terms of 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 that have now generally been replaced by cadmium-free compositions with equal performance. There are, however, several cadmium-containing alloys for special-performance applications that have been 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 that continue to grow are all centred around the NiCd 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. These are 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 vehicle (HEV), 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 ongoing 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 summarised in Table VII below.

Table VII: Worldwide consumer NiCd battery shipments by application, 2000-2004 (Takeshita, 2003, 2004, 2005)

	Millions of NiCd cells shipped				
Application	2000	2001	2002	2003	2004
Cordless Power Tools	419	325	450	469	574
Cordless Telephones	219	175	206	219	200
Household & Hobbies	412	548	586	602	400
Portable Audio/Visual	81	88	88	88	83
Cellular Telephones	88	25	10	5	<1
Camcorders	81	27	10	5	<1

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 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.

There is little doubt that the future of the NiCd 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 with NiCd batteries such as cost, cycle life, temperature operating range and susceptibility to overcharge. 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 HEVs, 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 HEVs and will capture a modest share of that market. Even though the American and Japanese manufacturers appear to favour 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 HEV market predict that there will be at least two million HEVs worldwide by 2010. Given the popularity of HEVs in the US, 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 sulphide and cadmium telluride (CdTe) based electronic devices 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. First Solar LLP in the US has developed cost-effective and high-speed production techniques for manufacturing CdTe solar cells, along with technology for recycling the 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 EC 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 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. With the current price of cadmium moving up past the US$2/lb 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 favourable, 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 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 HEVs, 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 US$0.20/lb. Prices increased in the spring and summer of 2001, but only to the US$0.50-US$0.60/lb level and then fell back again. During the autumn and early winter of 2003, prices once again rose, this time to the US$0.80/lb level and then retreated once again in the winter and early spring of 2004. During much of 2004, cadmium prices remained in the US$0.60-US$0.80/lb range. Finally, in February 2005, with continued demand from the Chinese NiCd battery industry and declining primary cadmium production, prices began to rise, 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 US$2.25/lb.

Current cadmium prices are now above the all time historical average price for cadmium of US$2.00/lb 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 prices will most likely continue to depend upon the on-going shortfall between cadmium supply and demand, and on whether sustained demand will continue to be realised from Chinese NiCd battery production and, perhaps in the future, from Korean, Indian or even Brazilian usage.

Outlook

The cadmium market today is considerably more positive than it was a year ago. Primary supply is still decreasing, but secondary supply is increasing to fill the gap between supply and demand. Excess cadmium stocks appear to have been depleted. Cadmium prices are now above the historical average prices of US$2.00/lb over the past 50 years and are continuing to climb. Cadmium applications are increasingly dominated by the NiCd 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 which is due in large part to cost advantages in labour, production and overheads. 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 China’s 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 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 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 cadmium products can be managed and, in the case of NiCd batteries, largely mitigated by the development of battery collection and recycling programmes such as those established by the Battery Association of Japan (BAJ) in Japan, the Rechargeable Battery Recycling Corporation (RBRC) in the US and Canada, and RECHARGE 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 the degree of recycling can be improved by collecting all chemistries, and that it is probably 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 elect to curtail cadmium production as many have in the past 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 utilised as a valuable by-product and then recycled so as to minimise any human health or environmental impact. The current increase in cadmium prices would favour the latter option, but some primary producers have already closed down their cadmium-production facilities, and others are uncertain about future cadmium prices. Secondary cadmium, mainly from the recycling of NiCd batteries, appears to offer the best prospects for both maintaining a stable cadmium price scenario and for minimising and best managing any environmental risks from cadmium products.