coverstory *By Dan Strassberg, Senior Technical Editor*

WE'VE MADE BATTERIES MUCH MORE ENVIRONMENTALLY FRIENDLY. MOST OF THE HARMFUL MERCURY IS GONE, AND RECYCLING PROGRAMS ARE IN FULL SWING. BUT THERE'S STILL MUCH WORK TO BE DONE.

BATTERIES CLEAN UP THEIR ACT

The batteries in 1999-model portable electronic products and cordless electric appliances are far more environmentally friendly than those that most manufacturers were installing five years ago. The improvements result from battery-industry initiatives, legislative cooperation, and the relentless march of technology. Still, this is no time for complacency. Each year, in the United States and Canada alone, users fail to recycle hundreds of millions of nickel-cadmium (NiCd) batteries that they should—and now easily could—recycle. Meanwhile, some promising new battery chemistries present environmental challenges of their own.

Probably the most important improvement in the environmental impact of small batteries has been the move from the NiCd chemistry to nickel metal hydride (NiMH). In a landfill, when an NiCd battery's case ruptures or corrodes, cadmium can leach into the water supply. Cadmium is a toxic heavy metal that can harm people and animals that ingest it. NiMH batteries don't contain cadmium, and, despite some concerns about the toxicity of nickel, the US Environmental Protection Agency (EPA) does not classify NiMH batteries as hazardous.

Photo courtesy Energizer Power Systems

NiMH batteries have substantially replaced NiCd units in new cellular and cordless telephones, laptop PCs, and related portable electronic products. Indeed, lithium-ion (Li-ion) and even newer lithium-polymer batteries have started to take over these electronic applications from NiMH.

TO EACH, ITS OWN

But the situation differs in other types of equipment. NiMH is just starting to make inroads into cordless power tools and vacuum cleaners, in which NiCd still dominates. Cordless appliances and tools are extremely sensitive to cost and reliability. Operating time between recharges—a key attribute of NiMH and Li-ion—is less important. What's more, NiMH-battery suppliers say that NiMH is now at or approaching cost parity with NiCd if you compare the watt-hours per dollar that cells of a given size supply. When manufacturers first marketed NiMH cells, they offered approximately 60% more storage capacity than same-size NiCds, but NiCd suppliers claim to have narrowed that edge to approximately 15%.

Although NiMH has established an enviable reliability record in electronics, some cordless-product manufacturers say that it has yet to establish its reliability in motor-drive applications. These experts assert that reliability in powering electronic devices does not guarantee reliability in power tools. Other manufacturers disagree. They insist that more than enough data exists to demonstrate NiMH's reliability for driving small motors.

Nevertheless, battery design involves trade-offs between energy density (usually measured in watt-hours per kilogram) and peak power output. Most NiMH cells are optimized for energy storage. Manufacturers may have to produce different cells for different classes of service, although, so far, manufacturers have largely refrained from taking this step in batteries for handheld products.

Portable-appliance motors draw order-of-magnitude-higher average currents than do typical electronic circuits. Cell phones draw a few watts; notebook PCs draw about 20W. Electric drills, on the other hand, can draw 200W peak and 60W average while making holes. Because batteries supply a fairly constant voltage under varying loads, output current varies a little more than linearly with output power. But self-heating is proportional to current squared, so temperatures in batteries for motor-drive applications can rise two orders of magnitude more than those in electronic-device batteries. Moreover, power-tool batteries are subject to more severe shock and vibration than are batteries in electronic products.

AT A GLANCE

- The US Battery Act of 1996 helped to overcome obstacles to recycling NiCd batteries. Those roadblocks encouraged users to send the batteries to landfills—the worst possible means of disposal.
- The battery industry now operates a voluntary recycling program for NiCd batteries. In its second full year, 1998, the program recycled approximately 25% of eligible batteries.
- Meanwhile, lead-acid-battery manufacturers claim a nearly 95% recycling rate for the lead in their (mostly larger) batteries.
- Newer chemistries, especially NiMH and several lithium-based formulations, pose less of a threat than NiCd and lead acid but still present environmental challenges.

NiMH FOR HYBRID ELECTRIC CARS

Notwithstanding the concern about high currents, several companies have developed and are evaluating large NiMH batteries for use in hybrid electric vehicles (HEVs). A typical HEV uses a small internal-combustion engine to charge a battery that drives an electric motor that propels the vehicle. Aside from chemistry, however, NiMH HEV batteries have little in common with NiMH appliance and cordless-tool batteries. Nevertheless, HEV batteries must supply hundreds of amperes when the vehicle is accelerating and must also accept large currents during dynamic braking. Designers of small batteries that must reliably deliver 10A or thereabouts can learn something from HEV-battery designs.

In such areas as uninterruptible power supplies (UPSs), emergency-lighting equipment, and cordless electric lawn mowers, small sealed-lead-acid (SSLA) batteries continue to play important roles. These applications benefit from SSLA's low self-discharge rates and, unlike handheld devices, can usually tolerate SSLA's modest energy density.

Proponents of battery recycling are quick to point out that a recycled NiCd battery is friendlier to the environment than a worn-out (spent) NiMH battery in a landfill. Inmetco, the company that recycles NiCd batteries for the Rechargeable-Battery-Recycling Corp (RBRC), uses a recovery process that yields nickel and cadmium of high purity for use in new batteries. RBRC is a nonprofit corporation that the rechargeable-battery industry established in 1994 to manage the North American NiCd-battery recycling program. Inmetco's process even ensures that the plastic parts become raw materials for the manufacture of new plastic products. Virtually nothing harmful finds its way into the water supply.

CHARGE UP TO RECYCLE

RBRC designed the US and Canadian Charge Up to Recycle NiCd-battery-recycling program. More than 200 manufacturers and resellers of NiCd batteries and products that use the batteries support the RBRC. The recycling program began in earnest in late 1996. Today, you can find RBRC recycling containers in more than 20,000 locations throughout the United States and Canada. Most of these locations are retail stores that sell NiCd batteries and products that use the batteries.

High-volume public- and private-sector users of NiCd batteries also act as recycling depots. Examples are metropolitan police departments that use large numbers of two-way radios. You can find the location of a recycling depot near you by calling 1-800-822-8837.

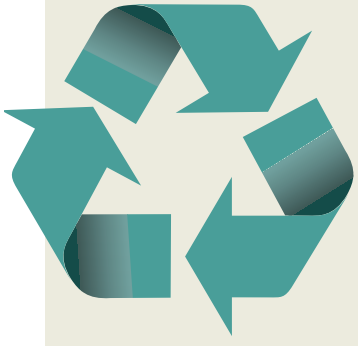
Estimates of the number of NiCd cells that reach the end of life in any year are inexact, but a reasonable estimate for the United States and Canada is 400 million. Part of the problem with the estimates is that most people don't recycle individual cells; they recycle batteries that contain three to 16 cells. Unless you know the number of cells in each battery, you have a problem with counting cells. Officials at RBRC think that the average is approximately six cells per battery. The corporation estimates that it recycled 100 million of those cells in 1998. The RBRC expects to double the recycled percentage to 50% by 2002 and hopes to recycle 80% of spent NiCd cells in 2005.

Achieving the current level of success took some doing. In 1996, after two years of operation, the RBRC had designed a sensible, cost-effective recycling program. Still, the organization found that its implementation efforts were stymied. The culprits weren't greedy corporations or an uncaring public. Instead, the very regulations that the federal government had set up to control toxic-waste hazards were at fault.

Even though the batteries posed a hazard only if they *weren't* recycled, the regulations required recycling companies to treat the devices as hazardous waste. This

CHASING DOWN THE TRUE MEANING OF THE CHASING ARROWS

The best-known symbol of the environmental movement is the three "chasing arrows." Unfortunately, those arrows have now acquired so many related but subtly different meanings that you can have a hard time understanding what the symbol means on any product. What's more, situations exist in which the similar symbols can suggest that you do the exact opposite of what the people who put the symbol on the product want you to do.



As most people understand the chasing-arrows symbol, it means that the product within the package on which the symbol appears is made of recycled materials. The product also can and should be recycled. However, if the symbol appears on the product (as opposed to the packaging), the symbol *may* (but does not necessarily) mean that you are violating the law if you send the product to a landfill. By law—at least in some places—you *must* recycle products that bear the chasing arrows.

Now consider three cylindrical metal objects—an empty soup can; a small sealed-lead-acid (SSLA) cell removed from, say, a cordless electric lawn mower; and a nickel-cadmium (NiCd) cell. To a casual observer, all three items can appear similar. Although the empty can weighs less than the batteries, all three are cylindrical, are more or less the same size, and appear to be made of metal.

You *should* recycle all three items; however, many places have no legal penalties for failing to recycle one or more of them. In only a few places are you likely to get into trouble for failing to recycle the soup can. In more places, you may be subject to penalties for failing to recycle the NiCd cell. And, in a still larger number of places, penalties may exist for failing to recycle the SSLA cell.

How the SSLA cell makes its way to a recycler depends on where you live. Approximately two dozen companies throughout the United States and Canada reclaim the materials in lead-acid batteries. As for the NiCd cell, the proper way to handle it is to place it in a Rechargeable-Battery-Recycling Corp (RBRC) container, although high-volume industrial users may deal directly with reclamation facilities. The precise fate of the soup can is a purely local issue, however.

DON'T CONFUSE THE USERS

Despite the desirability (and in some cases, the legal imperative) of dealing with each item in the manner appropriate to it, all three items carry the chasing arrows. Battery Council International (BCI) says that lead-acid batteries should carry the chasing arrows. The Portable Rechargeable Battery Association (PRBA) and the RBRC say that *only* NiCd cells and batteries should carry the RBRC symbol, which is based on the chasing arrows (**Figure A**).

Furthermore, the PRBA and the RBRC say that *no* type of battery that you might confuse with NiCd cells or batteries should contain a symbol that you could confuse with the RBRC logo. Although the RBRC has done a good job of designing a logo with a distinctive appearance, it's still not difficult to confuse the chasing arrows with the RBRC logo. The chasing arrows are *part* of that logo.

Besides the arrows, the RBRC logo contains a picture of a battery and the letters "NiCd." The logo also incorporates a bold circle bearing the RBRC's toll-free number. Because the RBRC program covers Canada as well as the United States, all labeling must appear in French as well as English. It was the RBRC's good fortune that the word "recycle" is the same in both languages.

Besides the chasing arrows, lead-acid batteries and cells must also carry the letters "Pb." Although having chemical symbols on both lead-acid and NiCd batteries makes confusion between the two types less likely, many millions of cells with older and less descriptive markings will continue in service for years. Therefore, confusion between the devices will be an issue well into the 21st century.

Remember that the subject is *trash*. When dealing with trash, how many people distinguish among NiCd cells, SSLA cells, "tin" cans, and aluminum cans? Perhaps the people at your town dump are trained to make the distinction. The next time you complain about how much your town pays its trash collectors, remember that two of the things that keep hazardous substances out of your drinking water are the sharp eyes and quick thinking of these public servants.

Figure A

NiCd cells and batteries take various forms. Sometimes, the cells are concealed within larger products. In the United States and Canada, the batteries (or the products, if you can't easily remove the batteries) must now bear the logo (upper right) of the Charge-up to Recycle program.

rule made it economically unfeasible to collect and transport the batteries for recycling. The rule applied throughout the United States except in a handful of states that had passed separate hazardous-waste laws.

Yet, because *new* batteries aren't waste, it was (and is) perfectly legal to ship them in quantities identical to those that were illegal for spent batteries. People who know even a little about NiCd batteries know that, as long as the battery cases remain intact, spent batteries present no greater hazard than do new ones. Moreover, even if the case ruptures, the cause of the most serious hazard is the leaching action of water. That cause does not exist if the batteries stay dry.

In addition, neither the federal nor the state regulations applied to private individuals. So, people who removed worn-out NiCd batteries from service had no options except to hoard the useless devices or place them in the household trash. Therefore, regulations that were supposed to protect the public from toxic wastes effectively forced people to dispose of batteries in the way that did the most ecological harm.

It's easy to blame an inept government bureaucracy for such senseless rules. However, the real culprits were the private citizens and organizations that pressured government officials into enacting those rules too quickly. A little thought about the categories of hazardous waste could have saved enormous amounts of wheel-spinning—and time. Without those delays, the RBRC program could have begun two years earlier, saving several hundred million NiCd cells from moldering in landfills and potentially polluting the water supply.

Putting the situation right required an act of Congress. On May 13, 1996, the Battery Act (technically, the Mercury-Containing and Rechargeable-Battery Management Act of 1996) took effect. A

BATTERY CONTACTS

For information on the environmental impact of batteries, battery recycling, and rechargeable batteries for portable electronic products and cordless appliances, circle the appropriate numbers on the Information Retrieval Service card or use *EDN*'s InfoAccess service. When you contact any of the following organizations and manufacturers directly, please let them know that you read about them in *EDN*.

Battery Council International (BCI)
Chicago, IL
1-312-644-6610
fax 1-312-321-6869
Circle No. 313

Battery Specialties
Costa Mesa, CA
1-619-573-0774
fax 1-619-573-0776
Circle No. 314

Black and Decker
Towson, MD
1-800-544-6986, 1-410-716-3900
fax 1-410-716-3053
www.blackanddecker.com
Circle No. 315

Energizer Power Systems
Gainesville, FL
1-904-462-4420
www.energizer.com/products/rechargeables
Circle No. 316

Florida Educational Seminars Inc
Boca Raton, FL
1-561-367-0193
fax 1-561-367-8429
www.subcomm.com/FES
Circle No. 317

Hawker Energy Products Inc
Warrensburg, MO
1-800-964-2837
fax 1-800-283-2948
www.hepi.com
Circle No. 318

Inmetco
Ellwood City, PA
1-724-758-2800
fax 1-724-758-2845
www.inmetco.com
Circle No. 319

MGE UPS Systems
Costa Mesa, CA
1-714-557-1636
fax 1-714-557-9788
www.mgeups.com
Circle No. 320

Ovonic Battery Co
Troy, MI
1-248-362-1750
fax 1-248-362-0332
www.ovonic.com
Circle No. 321

Panasonic Industrial Corp
Secaucus, NJ
1-877-726-2228, 1-201-392-6464
www.panasonic.com
Circle No. 322

Portable Rechargeable Battery Association (PRBA)
Atlanta, GA
1-770-612-8826
fax 1-770-612-8841
www.prba.org
Circle No. 323

Rechargeable-Battery-Recycling Corp (RBRC)
Gainesville, FL
1-352-376-9367
fax 1-352-376-5942
www.rbrc.com
Circle No. 324

Sanyo Energy (USA) Corp
San Diego, CA
1-619-661-6620
fax 1-619-661-6743
www.sanyo.com
Circle No. 325

Tadiran Electronic Industries
Port Washington, NY
1-800-537-1368, 1-516-621-4980
fax 1-516-621-4517
www.tadiranbat.com
Circle No. 326

Toxco
Anaheim, CA
1-714-630-8378
fax 1-714-630-1014
www.toxco.com
Circle No. 327

US Environmental Protection Agency (EPA)
Washington, DC
1-800-424-9346
www.epa.gov
Circle No. 328

Varta Batteries Inc
Elmsford, NY
1-914-592-2500
fax 1-914-345-0488
www.varta.com
Circle No. 329

SUPER CIRCLE NUMBER
For more information on the products available from all of the organizations and manufacturers listed in this box, circle one number on the reader service card. *Circle No. 330*

few of the law's major requirements are:

- Batteries of regulated types must be easily removable from consumer products manufactured after May 13, 1997. "Easily removable" means removable with the use of nothing more than common household tools. Regulated batteries include NiCds and certain SSLAs. In addition, the Battery Act empowers the EPA to add additional types of batteries to the list.
- Product manufacturers may petition the EPA for an exemption from the easy-removability requirement if the manufacturers can show that complying would violate other public or private standards or pose a threat to human health or safety or the environment.
- Regulated batteries must bear a recycling symbol, usually the three "chasing arrows." (Unfortunately, the meaning of the symbol is not always clear; see **sidebar** "Chasing down the true meaning of the chasing arrows.")
- Regulated batteries must be marked with their principal chemical components (NiCd, for example, or Pb—for lead).
- A product that contains nonremovable SSLA batteries must be marked "Contains sealed-lead battery. Battery must be recycled."
- This labeling must also appear on the packaging of consumer products that contain nonremovable SSLA batteries.
- No municipal, state, or federal government or government agency may enforce a removability or labeling requirement that differs from that in the Battery Act.

You may ask why there is no program to add a refundable deposit to the price of NiCd batteries. If you even mention deposits to Norm England, president of the Portable Rechargeable-Battery Association (PRBA), you had better be prepared for a fight. England spent 15 years in the plastics industry. He knows all about deposits on bottles and cans. England bristles at the suggestion that battery manufacturers ever even discussed deposits.

"Never happened," he snaps. Doing so, he argues, would probably invite federal prosecution of battery manufacturers for

MEMORY EFFECT? NO, VOLTAGE DEPRESSION

A good way to agitate a representative of a battery manufacturer—particularly a manufacturer of nickel-cadmium (NiCd) cells—is to mention the "memory effect." Some try to change the subject, others deny that the effect exists, and still others say that the effect may be a problem with competitors' products but not with their own.

Many users of rechargeable batteries believe that the effect exists. These users claim that if you repeatedly recharge NiCd batteries before fully discharging them, you reduce the amount of energy the batteries can store. Most battery manufacturers insist that memory effect is an urban legend—that stories about it have been repeated so often that nobody believes the denials. In fact, nickel-metal-hydride's (NiMH's) reputation for immunity to the memory effect at least partly accounts for the chemistry's popularity.

Whereas battery manufacturers generally agree that the memory effect is fiction, most concede that you might confuse a real phenomenon called "voltage depression" with memory effect. However, according to legend, the memory effect is irreversible, whereas voltage depression is fully reversible.

Should voltage depression occur, whether you notice it in a battery-powered product depends strongly on the product's design. According to Energizer Power Systems, one type of product in which the effect is particularly troublesome is handheld camcorders.

A DROP NEAR THE END

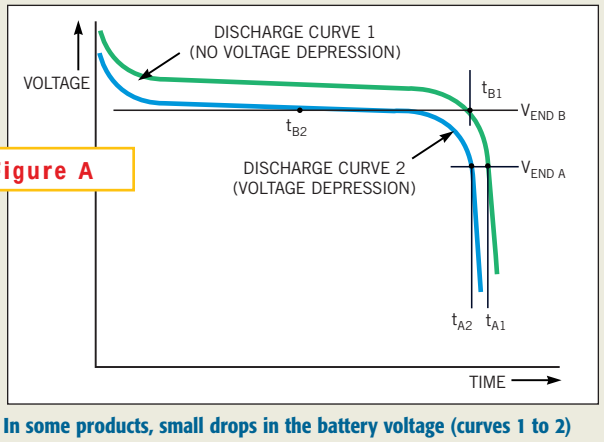
NiCd, NiMH, and several other types of rechargeable batteries exhibit output voltages that hold relatively constant as you discharge them until they near full discharge (**Figure A**). As the batteries approach the point at which you must recharge them, their output voltage drops more rapidly.

Products whose design tolerates a lower battery voltage ($V_{END\ A}$ in the **figure**) as a percentage of the battery's nominal output voltage offer several advantages. Such products not only squeeze out marginally more operating time between charges, but also are less affected by phenomena that depress the battery voltage.

In a product that accepts large percentage variations from nominal battery voltage, voltage depression only minimally shortens the operating time between charges. That is, the difference between t_{A1} and t_{A2} is small. Compare this small difference with the large difference between t_{B1} and t_{B2}). This large difference is what you'd observe in a product that ceases to function properly when the battery voltage falls only slightly below nominal.

Repeatedly recharging an NiCd battery without deeply discharging it can cause voltage depression (Curve 2 in the **figure**). The cure is to deeply discharge the battery—as long as you don't discharge it so fully that the voltage across one or more cells reverses. Manufacturers claim that voltage depression does not affect NiMH batteries, or, if it does, the effect is much smaller than in NiCd. Also, voltage depression is fully reversible and doesn't affect a battery's cycle life—the number of charge/discharge cycles the battery can endure before you have to replace it.

Figure A



In some products, small drops in the battery voltage (curves 1 to 2) end normal operation. In such products, voltage depression significantly shortens the period of operation between charges ($t_{B2} \ll t_{B1}$). In a product that tolerates a wider range of battery voltages, the same degree of voltage depression has hardly any effect ($t_{A1} \approx t_{A2}$).

collusion to raise prices, a violation of antitrust laws.

Moreover, the makers of most small rechargeable batteries have no interest in seeing deposits added to the price of their products. Deposits would just drive customers into the arms of suppliers of primary (that is, nonrechargeable) batteries, of which the most common type is alkaline. Alkaline batteries are quite environmentally friendly, especially now that manufacturers have modified the manufacturing processes to eliminate all but trace amounts of mercury. Still, replacing rechargeable batteries with nonrechargeable ones would not help to improve the environment. In fact, the result would be quite the opposite.

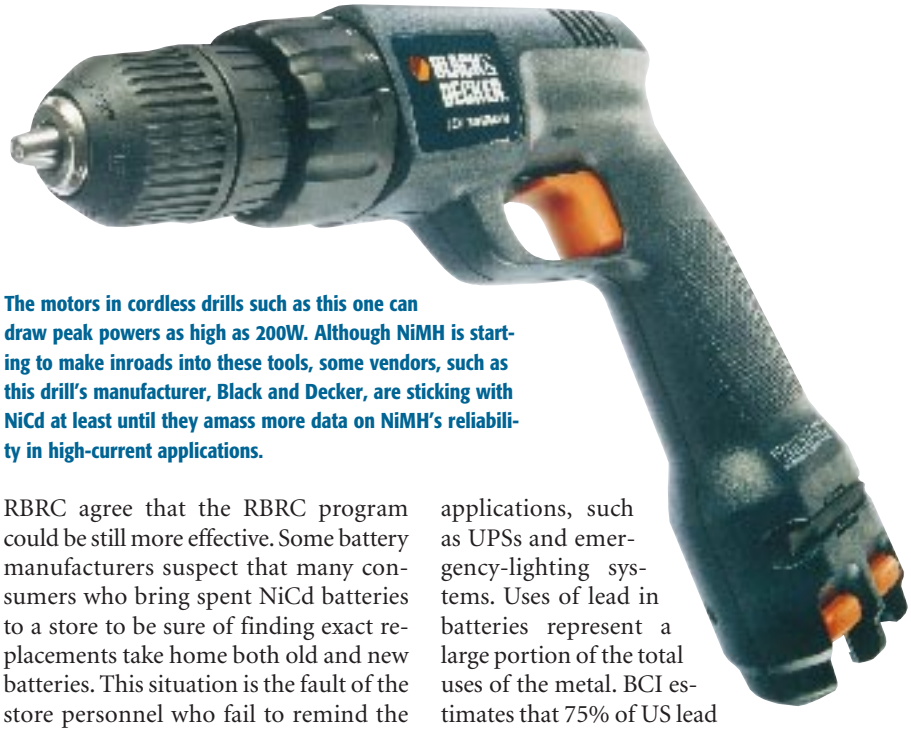
If deposits are ever added to the prices of NiCd cells, it will be because of legislation at the state level. But England is confident that states will enact no such legislation. He points out that, since 1988, no state has enacted a "bottle law" requiring deposits on soft-drink and juice containers. He says that, in the states that have them, such laws have a terrible reputation with everyone they affect—bottlers, retailers, and consumers. He also claims that the laws have not reduced the litter that they were enacted to reduce.

GETTING THE LEAD OUT

Notwithstanding the NiCd-battery industry's opposition to deposits, deposits are a part of a model lead-acid-battery-recycling law that was drafted by Battery Council International (BCI), a lead-acid-battery trade association. BCI favors enactment of state laws that impose a mandatory $10-per-battery deposit. Lead-acid-battery-deposit laws exist in only a dozen states, some of which make the deposits voluntary on the part of the retailer. Moreover, the most common deposit is only $5 per battery. Still, BCI estimates that recycling of lead in batteries approaches 95% in the United States.

Meanwhile, England points with pride to the 25% recycling rate that the RBRC's recycling program achieved in just its second full year of operation. He believes that those results demonstrate beyond a doubt that the battery industry's voluntary efforts are far more effective than any deposit program could be.

Nevertheless, both the PRBA and the RBRC agree that the RBRC program could be still more effective. Some battery manufacturers suspect that many consumers who bring spent NiCd batteries to a store to be sure of finding exact replacements take home both old and new batteries. This situation is the fault of the store personnel who fail to remind the customer to drop off the old batteries in the RBRC container. According to RBRC Executive Vice President Ralph Millard, the RBRC's battle to get store personnel to remind customers about recycling will never end. Work-force turnover is high in retail businesses, and most store employees face heavy demands.



The motors in cordless drills such as this one can draw peak powers as high as 200W. Although NiMH is starting to make inroads into these tools, some vendors, such as this drill's manufacturer, Black and Decker, are sticking with NiCd at least until they amass more data on NiMH's reliability in high-current applications.

LITHIUM AND UNDERGROUND FIRES

If you think that the only environmental problem with batteries relates to the use of heavy metals in some chemistries, you are incorrect. Although Li-ion batteries are free of heavy metals (lithium has a low atomic number), lithium's high degree of chemical activity can create environmental problems. When exposed to water, which is present in most landfills, the metal can burn, causing underground fires that are difficult to extinguish. Because the newer lithium-polymer chemistry contains more metallic lithium than Li-ion does, lithium-polymer batteries can be more difficult to handle. Recycler Toxco operates a facility for reclaiming the materials in batteries that contain lithium.

Lead, a toxic heavy metal, has been a constituent of common rechargeable batteries longer than any other metal. Automotive storage batteries use the lead-acid chemistry. More recently, SSLA batteries have found their way into many common applications, such as UPSs and emergency-lighting systems. Uses of lead in batteries represent a large portion of the total uses of the metal. BCI estimates that 75% of US lead use is for batteries.

Five states ban disposal of lead-acid batteries, and 38 have enacted laws governing their recycling. According to BCI, the 1994 recycling rates for lead-acid batteries, which approached 95%, exceeded those for aluminum cans (70%), newspapers (60%), and glass bottles (40%).

UPS manufacturer MGE uses sealed-lead-acid batteries in most of its UPSs. The company offers minimal-cost replacement of any UPS whose lead-acid batteries require replacement. Even though the batteries within the units are sealed and present no hazard, most customers don't want to deal with opening the units and replacing the batteries. Barry Eisenberg, product manager for the company, says that most of these customers are afraid of coming into contact with the sulfuric acid in the batteries.

"For all practical purposes, that can't happen in a UPS that uses sealed batteries, and that includes essentially all UPSs," says Eisenberg.

THE QUICK(SILVER) AND THE DEAD

Another toxic heavy metal that once was part of many batteries but has now all but disappeared is mercury. Some small batteries in cameras and hearing aids used small amounts of mercury by design. The United States no longer permits sale of such batteries.

Other more common batteries, such as alkaline, the most popular type of nonrechargeable battery, once contained more than trace amounts of mercury. The manufacturers added small amounts of mercury to achieve the desired characteristics.

Early in this decade, under pressure from environmentalists, the battery industry reengineered its manufacturing processes. The result is that the only mercury that remains in alkaline batteries is in the impurities in other materials. The battery characteristics no longer depend on the presence of mercury. The process modifications neither degraded the battery performance nor significantly raised the cost. By law, batteries sold in the United States may no longer contain more than trace amounts of mercury.

Despite the heat-generating high currents that their motors draw, some cordless electric drills now use NiMH batteries (courtesy Energizer Power Systems).

CHARGE UP TO CHARGE UP

The design of chargers and battery packs has become somewhat more complex as a result of the changes in battery chemistry. The added complexity especially affects products that have used NiCd but now use NiMH, Li-ion, or lithium polymer. First of all, both NiCd and NiMH produce a nominal output voltage of 1.2V per cell, whereas the lithium chemistries produce a nominal 3.6V per cell. Fortunately, to manufacture small rechargeable batteries, manufacturers combine cells that are produced by the hundreds of millions. They place these cells into batteries, or "battery packs," that they produce in much smaller quantities. Often, the "smaller" quantities reach hundreds of thousands or millions, however.

To design a new battery pack, you can sometimes change from NiCd to NiMH simply by replacing the NiCd cells with NiMH cells. The result is usually a battery with greater capacity between charges than the original. Greater capacity is almost never a problem, but the NiMH battery's higher cost can be a problem. If a mechanical redesign of the battery pack is feasible, the solution to the cost problem might be to substitute smaller cells, say four-fifths C, or "Sub C," for C. The smaller NiMH cells offer capacity close to that of the larger NiCd cells at a price approaching that of the NiCd cells. An added advantage of a redesign can be reduced sensitivity to voltage depression (see **sidebar** "Memory effect? No, voltage depression").

A more subtle problem is NiMH cells' greater sensitivity to elevated temperatures. Particularly if the charge regime includes a quick-charge mode, the NiMH charger must usually safeguard against overcharging and battery overtemperature. In most cases, NiCd chargers need no such safeguards. A simple safeguard technique that some manufacturers use is to include a thermistor in the battery pack. The charger monitors the battery temperature via the thermistor (often with simple circuitry) and cuts off charging if the temperature becomes too high.

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COMPATIBILITY AND CONFUSION

Unless designed to handle both battery types, a charger that monitors the battery temperature in this way most likely works only with NiMH batteries. Older NiCd battery packs don't include the temperature sensor that the charger needs to operate. Thus, chargers designed for the older batteries will be unable to monitor the battery temperature and won't work with NiMH batteries. Industrial customers that add NiMH-powered devices to their tool inventories but that want to delay NiCd replacement until the old batteries wear out need separate NiCd and NiMH chargers. Otherwise, the customer must immediately replace all NiCd batteries or must replace all chargers with new ones that handle both battery types.

The charger-design problem can become still more complex if you switch a product from NiCd (or NiMH) to one of the lithium chemistries. Lithium cells have a terminal voltage three times as high as those of NiCd or NiMH cells. If you design a product in expectation of a future change to a lithium chemistry, you might make the nominal battery voltage a multiple of 3.6V. This approach lets you change chemistries by reducing the number of cells by two-thirds or placing groups of the higher voltage lithium cells in parallel. If these approaches don't work, the product—not just the battery pack—probably requires a major redesign.

A new technology simplifies charger designs in such situations. "Smart batteries" contain sophisticated ICs that communicate with the charger and, with other advanced ICs in the charger, adapt the charger's characteristics to those of the battery. Incorporating such ICs in the battery pack can make it simpler for one charger to safely charge several types of batteries. The charger and the smart batteries must, of course, be designed to work together. □

Reference

1. US Environmental Protection Agency, "Implementation of the mercury-containing and rechargeable battery management act," EPA document no. 530-K-97-009, 1997, www.epa.gov/epaoswer/osw/hazwaste.htm.