**Nickel-based Batteries**

The following section describes nickel-based batteries, and we begin with nickel-cadmium (NiCd), an older chemistry for which extensive data is available. Much of these characteristics also apply to nickel-metal-hydride (NiMH), as these two systems are close cousins. The toxicity of NiCd is limiting this solid and robust battery to specialty applications.

**Nickel-cadmium (NiCd)**

The nickel-cadmium battery, invented by Waldmar Jungner in 1899, offered several advantages over lead acid, but the materials were expensive and the early use was restricted. Developments lagged until 1932 when attempts were made to deposit the active materials inside a porous nickel-plated electrode. Further improvements occurred in 1947 by trying to absorb the gases generated during charge. This led to the modern sealed NiCd battery in use today.

For many years, NiCd was the preferred battery choice for two-way radios, emergency medical equipment, professional video cameras and power tools. In the late 1980s, the ultra-high-capacity NiCd rocked the world with capacities that were up to 60 percent higher than the standard NiCd. This was done by packing more active material into the cell, but the gain was met with the side effects of higher internal resistance and shorter cycle.

The standard NiCd remains one of the most rugged and forgiving batteries but needs proper care to attain longevity. It is perhaps for this reason that NiCd is the favorite battery of many engineers. Table 1 lists the advantages and limitations of the standard NiCd.

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| **Advantages** | Fast and simple charging even after prolonged storage  High number of charge/discharge cycles; provides over 1,000 charge/discharge cycles with proper maintenance  Good load performance; rugged and forgiving if abused  Long shelf life; can be stored in a discharged state  Simple storage and transportation; not subject to regulatory control  Good low-temperature performance  Economically priced; NiCd is the lowest in terms of cost per cycle  Available in a wide range of sizes and performance options |
| **Limitations** | Relatively low specific energy compared with newer systems  Memory effect; needs periodic full discharges  Environmentally unfriendly; cadmium is a toxic metal and cannot be disposed of in landfills  High self-discharge; needs recharging after storage |

**Table 1: Advantages and limitations of NiCd batteries**

**Nickel-metal-hydride (NiMH)**

Research of nickel-metal-hydride started in 1967; however, instabilities with the metal-hydride led scientists to develop the nickel-hydrogen battery (NiH) instead. Today, NiH is mainly used in satellites.

New hydride alloys discovered in the 1980s offered better stability and the development of NiMH advanced in earnest. Today, NiMH provides 40 percent higher specific energy than a standard NiCd, but the decisive advantage is the absence of toxic metals.

The advancements of NiMH are impressive. Since 1991, the specific energy has doubled and the life span extended. The hype of lithium-ion may have dampened the enthusiasm for NiMH a bit but not to the point to turn HEV makers away from this proven technology. Batteries for the electric powertrain in vehicles must meet some of the most demanding challenges, and NiMH has two major advantages over Li-ion here. These are price and safety. Makers of hybrid vehicles claim that NiMH costs one-third of an equivalent Li-ion system, and the relaxation on safety provisions contribute in part to this price reduction.

Nickel-metal-hydride is not without drawbacks. For one, it has a lower specific energy than Li-ion, and this is especially true with NiMH for the electric powertrain. The reader should be reminded that NiMH and Li-ion with high energy densities are reserved for consumer products; they would not be robust enough for the hybrid and electric vehicles. NiMH and Li-ion for the electric powertrain have roughly one-third less capacity than consumer batteries.

NiMH also has high self-discharge and loses about 20 percent of its capacity within the first 24 hours, and 10 percent per month thereafter. Modifying the hydride materials lowers the self-discharge and reduces corrosion of the alloy, but this decreases the specific energy. Batteries for the electric powertrain make use of this modification to achieve the needed robustness and life span.

There are strong opinions and preferences between battery chemistries, and some experts say that NiMH will serve as an interim solution to the more promising lithium systems. There are many hurdles surrounding Li-ion also and these are cost and safety. Li-ion cells are not offered to the public in AA, AAA and other popular sizes in part because of safety. Even if they were made available, Li-ion has a higher voltage compared to nickel-based batteries.

**Consumer Application**

NiMH has become one of the most readily available and low-cost rechargeable batteries for portable devices. NiMH is non-toxic and offers a higher specific energy than NiCd. Battery manufacturers, such as Sanyo, Energizer, Duracell and GP, have recognized the need for a durable and low-cost rechargeable battery for consumers and offer NiMH in AA and AAA sizes. The battery manufacturers hope to persuade buyers to switch to rechargeable batteries and reduce the environmental impact of throwaway primary cells.

The NiMH battery for the consumer market can be viewed as an alternative to the failed *reusable alkaline* that appeared in the 1990s. Limited cycle life and poor loading characteristics hindered its success.

What is of ongoing concern to the consumer using rechargeable batteries is the high self-discharge, and NiMH behaves like a leaky basketball or bicycle tire. A flashlight or portable entertainment device with a NiMH battery gets “flat” when put away for only a few weeks. Having to recharge the device before each use does not sit well. The Eneloop NiMH by Sanyo has reduced the self-discharge by a factor of six. This means that you can store the charged battery six times longer than a regular NiMH before a recharge becomes necessary. The drawback is a slightly lower specific energy compared to a regular NiMH. Other NiMH manufacturers such as ReCyko by GP claim similar results.

Table 2 summarizes the advantages and limitations of industrial-grade NiMH. The table does not include the Eneloop and equivalent consumer brands.

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| **Advantages** | 30–40 percent higher capacity than a standard NiCd  Less prone to memory than NiCd  Simple storage and transportation; not subject to regulatory control  Environmentally friendly; contains only mild toxins  Nickel content makes recycling profitable |
| **Limitations** | Limited service life; deep discharge reduces service life  Requires complex charge algorithm  Does not absorb overcharge well; trickle charge must be kept low  Generates heat during fast-charge and high-load discharge  High self-discharge; chemical additives reduce self-discharge at the expense of capacity  Performance degrades if stored at elevated temperatures; should be stored in a cool place at about 40 percent state-of-charge |

**Table 2: Advantages and limitations of NiMH batteries**