Battery Trade Offs for Mobile Hospital Carts

Current technologies provide four distinct battery chemistries for mobile applications; Nickel Cadmium [NiCd], Nickel-Metal Hydride [NiMH], Lithium-ion [various Li-ion] and Sealed Lead Acid [Pb-Acid or SLA]. Each has characteristics providing advantages in specific applications however none is optimum in all categories. Within this paper we will attempt to provide a summary view of the capabilities, advantageous and disadvantageous of each.

In each paragraph we will provide a ranking of the four chemistries. The ranking will be as quantitative as possible but in some instances may include a subjective factor.

The sources of this data are a variety of internet sites as well as journals and text books. Unfortunately not all sources agree in all regards. Also, data changes rapidly as technology develops. For these reasons we caution readers that this information is general in its context and is not meant to provide precise measure.

The summary of this paper will provide a summary of the paragraphs listed below with an opinion formulated through this data in regard to mobile hospital carts. We have a relatively unbiased view of the technology since our interest is the management of the power and is therefore not dependent on technology. The fundamental argument is that application requirements dictate the chemistry that is most appropriate. No chemistry will be fully compliant with all requirements of an application; there is typically one, however, that is more acceptable than the others. The user must decide the priority or the operational parameters and have a requirement specified that dictates the overall system performance.

Price per Unit of Energy

	Relative Cost
Lead Acid	x
NiCd	2x
NiMH	2.5x
Li-Ion	4x-5x

The above chart is a rough relative cost guideline. Cost varies depending on manufacturer, physical size and shape and, of course, technology development.

SLA is significantly less expensive than competing technologies for equivalent power capabilities.

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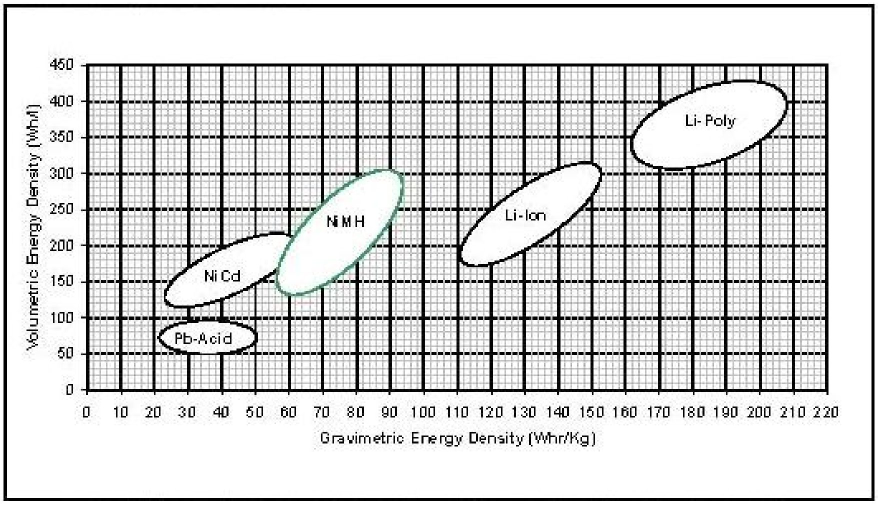
<u>**Energy Density Comparisons**</u>



The above chart show the range of the four various types of chemistries [Li-Ion is split between Li-Ion and Lithium Polymer]. Pb-Acid is the least dense per unit of energy and therefore is the heaviest for equivalent energy. Li-Poly is the densest per unit of energy and therefore is the lightest. The overall ranking of chemistries in regard to power per density is as follows.

1. Li-Ion
2. NiMH
3. NiCd
4. Pb-Acid

This indicates that Li-Ion is preferred in applications that prioritize weight reduction while requiring specific power availability.

<u>**Cycle Life**</u>

Cycle life various considerably in relation to

• Temperature	High temperatures v. low temperature
• Cycle type	Full discharge v. partial discharge
• Recharge	Battery manuf. compliant curves v. simple constant current source
• Usage	High percentage shelf v. constant usage, Periodic Maintenance

The following chart is simplified in that it provides a general relationship between the chemistries. Specific cycling capability is dependent on the above parameters.

	Relative Cycles
NiCd	1500
Li-Ion	1200
NiMH	1000
Pb-Acid	500-800

The definition of an "adequate cycle" and the corresponding charge retention is not specified [80% of initial capacity?]. NiMH, for example, has a cycle life of 1000 cycles however after approximately 300 cycles the capacity capability and the self discharge rates deteriorate rapidly. This deterioration however, is not accounted for in the above characteristics since, although deteriorated, the battery is still "usable" through to the approximately 1000th cycle.

Cycle life is also dependent on the battery receiving regular maintenance. Failing to apply periodic full charge cycles may reduce the Cycle Life by a factor of three; NiMH, Pb-Acid, Li-Ion.

Relative ranking of chemistries in regard to cycle life is

1. NiCd
2. Li-Ion
3. NiMH
4. Pb-Acid

Shelf Life

Shelf life is dependent on the self discharge rate of the battery chemistry. When a battery is shelved and not in use, it has an inherent internal resistance that discharges the battery. The following chart represents a relational view of the chemistries.

	Discharge Rate % per month
Pb-Acid	3%-4%
Li-Ion	5%-10%
NiMH	20%
NiCd	20%

This provides a rough guideline representing the ability for a battery to withhold its charge during a period without use. In the case of the Pb-Acid, the battery must be fully charged to meet this parameter.

Relative ranking of chemistries in regard to shelf life is

1. Pb-Acid
2. Li-Ion
3. NiMH
4. NiCd

Charge Capability

This parameter takes into account the speed with which a battery can be recharged to an essentially full state and the relative complexity with which the charge must be applied. Rechargeable batteries are routinely charged with very simplistic charging devices that do not effectively charge the batteries. Some chemistry's are more tolerant of simple chargers [although not optimizing the charge] while others must have sophisticated, more demanding, charge algorithms. Further, chemistry's vary with the ability to rapid charge.

	Charge Sophistication	Rapid Charge Capable?
Pb-Acid	Low	No
Li-Ion	High	Yes
NiCd	High	Yes
NiMH	Very High	Yes

Relative ranking of chemistries in regard to charge capability is

1. Pb-Acid
2. Li-Ion
3. NiCd
4. NiMH

Safety

Safety refers to the inherent safety of the battery chemistry in the following areas

- Over Charging — Can the chemistry remain in a charge state unattended?
- Thermal Stability — Is the chemistry thermally stable at various ambient temperatures?
- Need for Fusing Protection — Is fusing necessary to protect at potential high currents?

	Overcharge Tolerance	Thermally Stable	Fuse Protection Recommended
Pb-Acid	High	Yes	No
NiCd	Moderate	Yes	Yes
NiMH	Low	Yes	Yes
Li-Ion	Low	at low temp	Yes

Relative ranking of chemistries in regard to safety is

1. Pb-Acid
2. NiCd
3. NiMH
4. Li-Ion

Toxicity

	Toxicity	Recycle Status
Pb-Acid	Toxic Lead and acids, harmful to environment	Routine program available, 98% recycled in USA
Li-Ion	Low toxicity, can be disposed in small quantities	Programs available, Not routine
NiMH	Relatively low toxicity, should be recycled	Programs available, Not routine
NiCd	Highly toxic, harmful to environment	Programs available, Not routine

Recently it has been recommended that all batteries are recycled. Since Pb-Acid has a history of a successful recycling program it gains greater acceptability although its chemicals are more toxic than all except NiCd. Another recent issue has been transportation of Li-Ion batteries. Below a specified threshold of mass of the batteries transit is not governed. Above this threshold, however, there are governmental regulations that must be met prior to any legal transportation.

Relative ranking of chemistries in regard to toxicity is

1. Pb-Acid
2. Li-Ion
3. NiMH
4. NiCd

Load Current

	Peak	Best Result
NiCd	20C	1C
NiMH	5C	<.5C
Li-Ion	<3C	<1C
Pb-Acid	5C	.2C

The different chemistries available have different capabilities in regard to the amount of current it can provide to a load to operate within its operational guidelines. The value "C" is

> ***used to signify a charge or discharge rate equal to the capacity of a battery divided by one hour. Thus C for a 1600 mAh battery C would be 1.6 A, C/5 for the same battery would be 320 mA and C/10 would be 160 mA. Because C is dependant on the capacity of a battery the C rate for batteries of different capacities must also be different.***

The optimum current for optimal performance is varies.

Relative ranking of chemistries in regard to load current availability is

1. NiCd
2. NiMH
3. Li-Ion
4. Pb-Acid

Summary

The relative rankings are as follows.

Price	Energy Density	Cycle Life	Shelf Life	Charge Capability	Safety	Toxicity	Load Current
Pb-Acid	Li-Ion	NiCd	Pb-Acid	Pb-Acid	Pb-Acid	Pb-Acid	NiCd
NiCd	NiMH	Li-Ion	Li-Ion	Li-Ion	Li-Ion	Li-Ion	NiMH
NiMH	NiCd	NiMH	NiMH	NiCd	NiCd	NiMH	Li-Ion
Li-Ion	Pb-Acid	Pb-Acid	NiCd	NiMH	NiMH	NiCd	Pb-Acid

In reviewing the above chart it becomes obvious that the user of the battery needs to prioritize the requirements to make a comprehensive decision.

For example, using Mobile Hospital Carts, the priority of requirements might be as follows;

1. Safety
2. Price
3. Cycle Life
4. Shelf Life
5. Load Current
6. Charge Capability
7. Toxicity
8. Energy Density

This listing is highly subjective. Safety is considered to be paramount in a hospital environment while price, cycle life and shelf life reflect the total lifecycle cost of the battery. The load current determines how many devices might be powered from the battery; this might be an advantage but not necessarily a hard "requirement". The charge capability can be managed through the choice of a superior charging system and, although affecting price, it typically is more of a nuisance as it may require longer charge duration. The toxicity is relevant in that it either is or isn't toxic and since all are in some way toxic, they all have concerns. The ability to discard without undue problems would be an advantage but not of premium importance. The energy density seems to be the least important in that as long as the mobile cart is not unreasonably heavy and difficult to move, it is not a significant issue.

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Safety	**Price**	**Cycle Life**	**Shelf Life**	**Load Current**	**Charge Capability**	**Toxicity**	**Energy Density**
Pb-Acid	Pb-Acid	NiCd	Pb-Acid	NiCd	Pb-Acid	Pb-Acid	Li-Ion
Li-Ion	NiCd	Li-Ion	Li-Ion	NiMH	Li-Ion	Li-Ion	NiMH
NiCd	NiMH	NiMH	NiMH	Li-Ion	NiCd	NiMH	NiCd
NiMH	Li-Ion	Pb-Acid	NiCd	Pb-Acid	NiMH	NiCd	Pb-Acid

Using the above prioritizations, it seems that Pb-Acid [Sealed Lead Acid] has a distinct advantage. Considering the inherent safety and overall price, the Pb-Acid seems to provide the most appropriate choice for a cost conscience medical environment.

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