

Battery Chemistry Decisions Related to Mobile Hospital Carts

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Current battery technologies provide four distinct chemistries for mobile applications;

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|-------------------------|-------------------|
| 1. Nickel Cadmium | [NiCd], |
| 2. Nickel-Metal Hydride | [NiMH], |
| 3. Lithium-Ion | [various Li-Ion] |
| 4. Sealed Lead Acid | [Pb-Acid or SLA]. |

Each chemistry choice has characteristics providing advantages in specific applications however none is optimum in all categories. This paper will attempt to provide a summary view of the capabilities, advantages and disadvantages 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. Additionally, the 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 conclusion 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 in the management of the power and is therefore not dependent on the specific 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 based on the application and, in response, prepare a requirement that dictates the overall system performance resulting in a preferred battery chemistry.



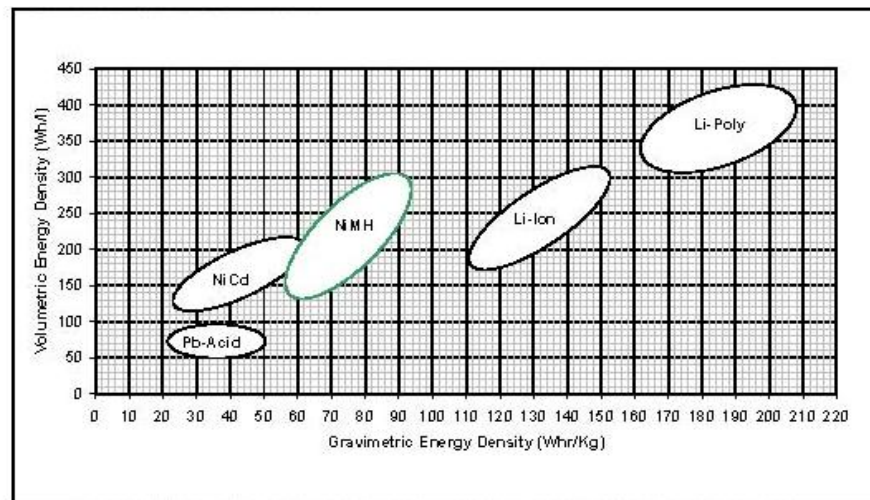
Price per Unit of Energy

Chemistry	Relative Cost
Pb- 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.

Pb-Acid is significantly less expensive than competing technologies for equivalent power capabilities.

Energy Density Comparisons



The above chart shows 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 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.

Cycle Life

Cycle life varies 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.

Chemistry	Relative Cycles
NiCd	1500
Li-Ion	300-1000 [depending on chemistry]
NiMH	300-800
Pb-Acid	200-700

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 up to 800 cycles, however after approximately 300 cycles both 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 800th 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.

Chemistry	Discharge Rate % per Month
Pb-Acid	3%-4%
Li-Ion	5%-10%
NiMH	20%-40%
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.

Chemistry	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

In addition, there exist practical limitations of rapid charge batteries for mobile cart applications. This feature is taken into account in the above ranking.

Mobile Medical Carts presently utilize battery packs with capacities in the range of 20 Amp Hours up to 90 Amp Hours to provide the long run times required by hospital staff during a typical work shift. Recharging the batteries requires the user to either be tethered to a wall outlet or the cart is not used for a period of time.

New battery chemistries hold promise of significantly shorter charge times over traditional Pb Acid chemistry. For example; cell phones, electric razors and cordless drills are charged in a very short period of time using Li-Ion or NiMH batteries. A cell phone may have a 1 Amp Hour pack with a 1 Amp charger [a one “C” rate; please reference the LOAD CURRENT discussion further on in this paper for a discussion on the definition of the term “C”]; providing a full charge in approximately one hour. Some of the new “18650” Lithium cell varieties may be charged at a 2 C rate (or even higher) without significant life degradation.

Battery Chemistry	Maximum Charge Rate
NiCd	.3C to 3C
Lithium (Various Types)	1C up to >2C
NiMH	1C
Pb Acid (SLA)	0.2C up to 0.3C

Mobile Carts typically do not benefit from the rapid charge capability due to the significant energy required for Mobile Cart applications; small batteries are more apt to benefit from rapid charging capabilities.

Consider a traditional 50 Amp Hour Pb Acid battery pack that will typically charge in about 4-5 hours with a 10 Amp/150 Watt charger. The same capacity battery pack made up of Lithium cells can theoretically charge in about an hour. The charger necessary to accommodate a one hour charge would



be a 100 Amp/ 1500 Watt on-board rapid charger. Unfortunately chargers of this horsepower are not available for use on Mobil Carts.

The charging systems presently available for Mobile Carts are in the range of 5 Amps/ 75 Watts up to 20 Amps/ 300 Watts; in some cases sharing that power with a computer system installed on the cart. A 10 Amp/ 150 Watt dedicated charger for the 50 Ah Li-Ion example above will charge the battery at a 0.2 C rate, resulting in 4-5 hours (about the same as an equivalent Pb Acid chemistry battery). Even a 20A/ 300 Watt dedicated charger results in 2.5 - 3 hours. This is less time than an equivalent Pb Acid battery but the impact is not as significant as it may appear from a quick analysis.

Therefore, at the large energy battery capacities required for Mobile Carts, rapid charge batteries may not result in faster charge times, due to practical limitations of on board charging systems.

Another practical limitation may be the use of removable batteries and remote charging stations. Remote charging systems can be used if the batteries are readily removable. This however, may create logistical concerns for both the Nursing community as well as the IT staff of a hospital.

Considering that there must be a constant resource of charging or charged batteries available and that someone must be available to “trade” the batteries from the cart in use to the battery charger this can become complicated. Further, the energy required in support of multiple charging systems may become relevant to a hospital that does not have ample circuits to dedicate the amperage necessary.

If, for example, there are 15 carts in an area and each cart has one battery available for each cart in use, this requires 30 total batteries and 15 under charge [worst case] at a given time. If the batteries are charged in four bay chargers, this would require four charges to be located in a given battery charge location. If the chargers used approximately 2 amps per bay or 8 amps total [providing an approximate C/2 charge for a 20 Amp Hour battery; an approximate charge time of 2.5 hours], there would be a need of approximately $8 \times 115 = 920$ watts per four bay charger or roughly 3700 watts total. This would result in an AC current need of approximately 32 amps. With dedicated 20 amp circuits this could be accommodated in two circuits. With shared circuits, this may take as many as 4 circuits to accommodate the charging requirements. This could be logistically difficult depending on the available power in the hospital infrastructure.

Therefore, the fast charge energy requirements may also have practical implications making it difficult to implement on a large scale.

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?



Chemistry	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

Chemistry	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 the transportation of Li-Ion batteries. Below a specified “threshold of mass” of the Lithium content, transit of batteries 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

Chemistry	Peak	Best Result
NiCd	$20 \times C$	C
NiMH	$5 \times C$	Less than ($C \div 2$)
Li-Ion	Less than ($3 \times C$)	Less than C
Pb-Acid	$5 \times C$	$C \div 5$

The different chemistries have different capabilities regarding the amount of current each can provide to a load device while operating within its performance 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 (regardless of chemistry) would be **1600 mA**, $C \div 5$ for the same battery would be **320 mA** and $C * 5$ would be **8000 mA**. Because C is dependent on the capacity of a battery, C for batteries of different capacities must also be different.

The optimum current for optimal performance varies between battery chemistries.

Relative ranking of chemistries in regard to load current availability is:

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

Summary

Based on the material presented above, the relative rankings of the various battery chemistries 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	NiCd	Li-Ion	NiMH
NiMH	NiCd	NiMH	NiMH	NiCd	NiMH	NiMH	Li-Ion
Li-Ion	Pb-Acid	Pb-Acid	NiCd	NiMH	Li-Ion	NiCd	Pb-Acid

In reviewing the above chart it becomes obvious that the application 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 priority list is highly subjective. The following arguments are the basis of the above list.

- 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.

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
NiCd	NiCd	Li-Ion	Li-Ion	NiMH	Li-Ion	Li-Ion	NiMH
NiMH	NiMH	NiMH	NiMH	Li-Ion	NiCd	NiMH	NiCd
Li-Ion	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.