# NEXT GENERATION LITHIUM ION BATTERY FOR TELECOMMUNCIATION DISTRIBUTED POWER SYSTEMS

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## INTRODUCTION

This paper examines the key development issues in designing a next generation lithium ion battery for distributed power applications in the telecommunications industry. We define distributed power as DC power plants in outdoor cabinet applications and smaller distributed DC power plant solution within central offices and satellite offices.

How to minimize costs and increase revenue is a major objective of the telecommunications business. With the increasing need to free up revenue generating space and minimize life cycle capital and operating costs in outside plants and central and satellite offices, the telecommunications industry is looking for a long-term cost-effective solution. A major component in achieving this objective is to identify new battery technologies that can address the needs for higher energy densities, reliability, safety, low maintenance costs and the ability to operate in a wide range of environmental conditions for long periods. The shortcomings of VRLA batteries have been well documented [1]. The introduction of alternative battery technologies such as lithium-based chemistries has raised hopes for a long-term cost-effective solution to the industry's needs. There are many lithium-based battery technologies in the world today, each with its own unique characteristics. Many of these chemistries and formats are not suitable for large capacity applications as required in the telecommunications industry. Lack of electronic controls is also an issue. Sophisticated electronic battery management systems (BMS) are a prerequisite to ensure system reliability, safety and longevity of the battery in a wide range of operating conditions. With the introduction of any new battery technology, validation of safety, performance and a sound business case is paramount. The purpose of this paper is to look at these important issues with respect a new lithium ion battery being developed by International Telecom Power (ITP).

### The Arguments For and Against Lithium Ion Batteries in Telecom Distributed Power Applications

With the introduction of more and more distributed power plants in the telecommunication industry, demand for batteries that can withstand a wide range of environmental conditions and have high energy densities is growing. In uncontrolled environments VRLA batteries often suffer premature and/or sudden capacity losses and have been known to go into thermal runaway. The capital cost of VRLA is also deceptive when one considers the total life cycle cost of plants (including maintenance), replacement and disposal costs of these battery systems. Lithium-based battery technologies offer a cost effective solution given their higher energy densities, longer life and low maintenance costs. In addition, the performance characteristics of some lithium-based batteries are very attractive offering high rate of discharge capabilities, a relatively flat discharge curve, no Coup-de-Fouet voltage drop and no venting of dangerous gases. More revenue-generating space, less maintenance, better performance and high reliability equals more opportunities to increase returns to shareholders.

If lithium looks so good, why haven't we seen greater deployment of this technology? The answer, we believe, has three parts. First, while lithium-based battery technology has been around for years, there are still relatively few suppliers of large capacity lithium-based batteries and even less that can meet the rigorous standards of the telecommunications industry. The second issue is price. Strictly on an initial capital cost basis, lithium batteries are more expensive than traditional lead acid batteries. This initial price shock, when combined with internal battles over CAPEX, overshadows the fact that in many telecom applications, lithium batteries can be far more cost effective on a total life cycle cost basis. The third issue is the introduction of new technology into critical networks. Companies are generally reluctant to be a first adopter on new technology and would rather wait and see what happens.

**DESIGN CONSIDERATIONS FOR A HIGH CAPACITY LITHIUM ION BATTERY FOR TELECOMMUNICATION APPLICATIONS**

**<u>Design Consideration #1:</u> Choose a core cell chemistry that is safe, has a proven track record, and has exceptional performance characteristics**

### i. Electrochemistry – All lithium batteries are not created equal

In the world today, there are many types and sizes of lithium cells consisting of varied chemistries and with a wide range of applications from cell phones and laptop computers to military, medical and other specialized uses. It is essential to have a good understanding of what each chemistry can and can not do under various conditions to ensure safety and performance. "Lithium batteries" include lithium ion, lithium polymer, lithium metal polymer and a host of other lithium derivatives and use different cathode materials such as cobalt, nickel manganese cobalt, manganese dioxide, sulphur dioxide, iron phosphate

Intimate understanding of the selected lithium cell chemistry is required to make sure that all aspects of the "battery" including the process, technology, product integration, battery management systems and testing provide a high performance, safe battery for its particular application. In the selection of the appropriate cell technology for a battery system (defined as an array of lithium ion cells in combination with a battery management system and enclosure) a cell with a proven operating and safety history and good long-term storage and temperature tolerance characteristic is key. Considering these factors, the cell we selected is an established, tried and tested, 18650 lithium ion cobalt cell mass manufactured by a tier one lithium ion cell manufacturer.

### ii. Safety is Paramount – Cell safety features

The 18650 lithium ion cell comes in a variety of capacity ratings. We chose 2.2Ah because of its long-term operating history, safety features, performance and proven storage characteristics.

This cell uses UL registered components (UL 1642) and is ROHS compliant. Built into each cell are the following patented safety features:

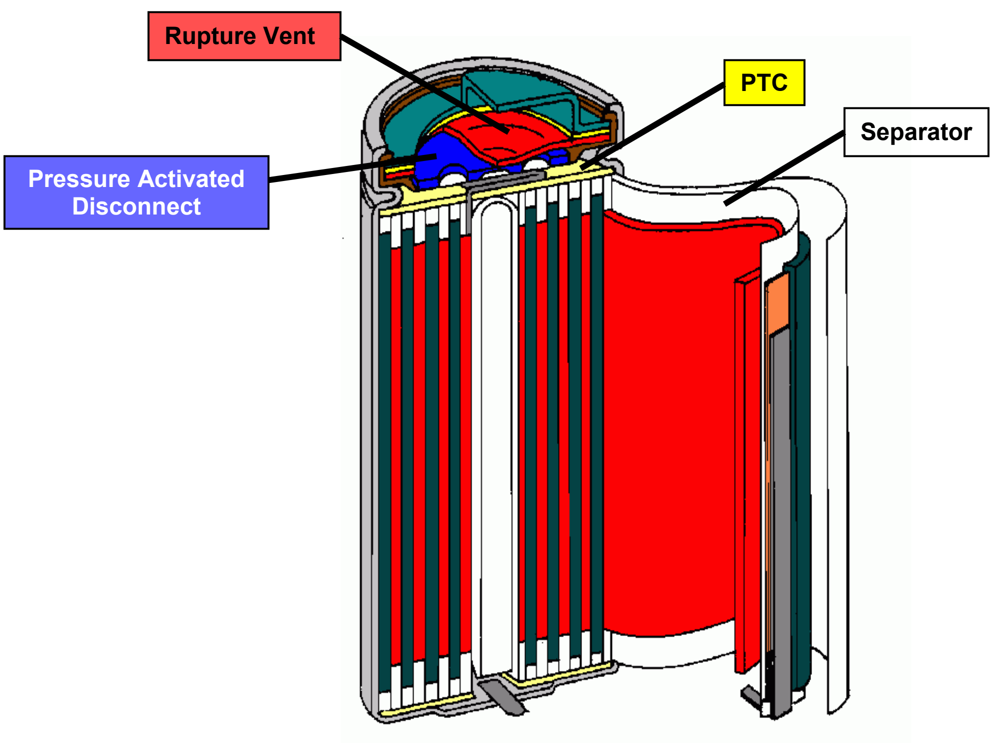



Figure 1 – Cutaway of 18650 Cell

***Rupture Vent***

In case of large internal pressure build-up (under thermal or mechanical abuse situations) the cell safely releases the gas pressure in a controlled manner so the cell does not explode.

***PTC (Polyswitch™)***

The PTC is built into the header of every cylindrical cell. It is used to limit currents in an over-charge condition (tripped by heat) and to protect against short circuit currents from a single cell.

***Separator***

The separator is a plastic porous material fitted between the anode and cathode electrodes. The separator melts above 120°C causing the pores to close, disabling the cell

***Disconnect Device***

The cells have a built-in electrical disconnect device (switch) for over-charge protection. This device is pressure-activated on overcharge and permanently opens the electrical connection to the outside thus stopping the overcharge before a possible safety incident. The cell is still fully sealed even after this device activates.

To validate these safety devices, the cells undergo a variety of UL testing where the cell's temperature and voltages are monitored under extreme event situation:

| | |
|---|---|
| Crush Test | The cell is crushed between two flat metal plates to a force of 3000 pounds. |
| Impact Test | The cell is placed on flat surface. A 5/8 inch diameter bar is placed across the centre of the sample and a 20 pound weight is dropped from a height of 24 +/-1 inches onto the sample. |
| Heat Test | The cell is heated in a gravity convection or circulating air oven with an initial temperature of 20+/-5ºC. The temperature is raised at a rate of 5 +/-2ºC per minute. The UL 1642 requirement is to a temperature of 130ºC. The cell reached 150 ºC and held for 10 minutes. |
| Over Current | The cell is subject to a charging current of 6A (~3 times normal) and a charging voltage of 15V. Test is run at ambient temperature of 20 +/-5ºC. UL 1642 standard requires normal charging voltage of 4.2V; the 18650 cell accepted a charge of 15V. |
| Short Circuit | The cell is short circuited by connecting the positive and negative terminals with a circuit load having a maximum resistance load of 0.1 ohm. Cell is discharged until it has reached a completely discharged state of less than 0.1 volts. The test is run at an ambient temperature of 55ºC. Our selected cell performed as well at 60ºC. |

**iii. Cell Reliability – Proven experience in the field**

The lithium ion cobalt 18650 cell has been in the marketplace for over 12 years. It is utilized by such companies and institutions as HP, Motorola, and the US military. To-date, there have been over 100,000,000 cells sold worldwide and, as discussed above, has patented cell safety technology with built-in redundant safety features. In addition, all cells are manufactured in ISO 9001 and 14001 certified facilities.

**iv. Performance**

The 18650 cell demonstrates excellent discharge characteristics, has very low impendence (allowing for very high discharge rate {C/1} with minimal loss of capacity), and has exceptional energy density of 496Wh/Litre or 182Wh/Kilogram. The cell also demonstrates a wide temperature operating range (from -20ºC to +65ºC), stores well, has very good depth of discharge characteristics (Figure 2) and requires no maintenance.

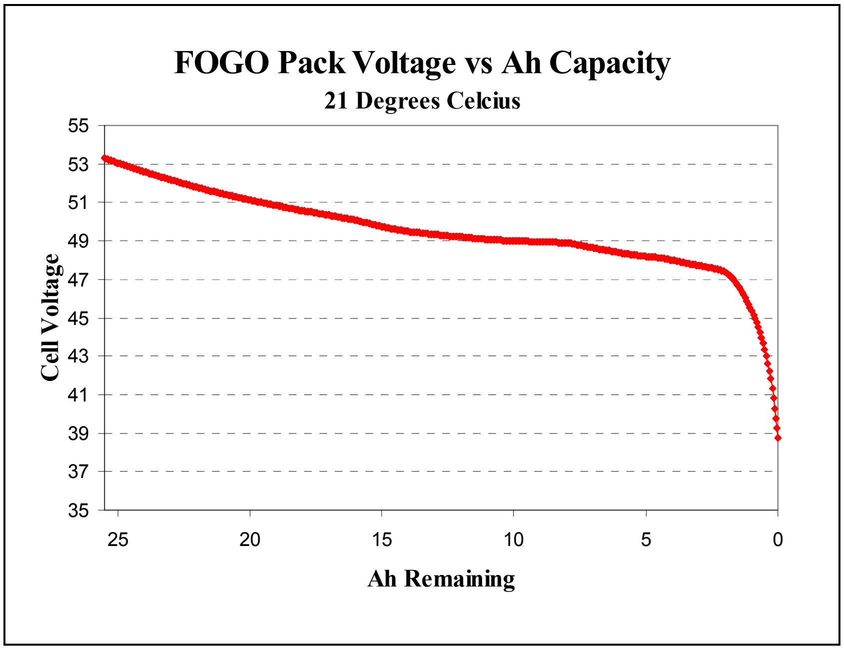



**Figure 2 – Discharge Curve Characteristics 18560 cell pack**

**Design Consideration #2: Design a State-of-the Art Battery Management System (BMS)**

Once we identified the lithium ion cell, we arranged them in series and parallel to meet the various voltage and capacity needs of the telecom industry. This "core" of cells is constructed in a manner designed to mitigate any propagation of individual cell failure and minimize capacity loss. We then developed a state-of-the-art battery management system. The BMS controls all cell function according to the manufacturer's specifications, manages all parameters impacting on the battery's performance and battery to battery communications, alarming, data logging of critical battery parameters and remote monitoring.

It is important to realize that the BMS is the top level of control and supervision. It looks at the total battery system but the BMS cannot be the only means of protection. For success you have to look at the battery system like an onion with multiple layers each overlaying the lower level. An effective BMS will provide a global view to the outside world and isolate the lower level functions from the outside. This allows for a modular and scalable system and makes it possible to easily customize the battery to meet specific customer requirements.

The control electronics must have access to temperature, voltage and current parameters at the cell level. Using this information the system makes operational decisions to ensure the safe operation of the cells and pack. The BMS is the first line of defence but not the only level of protection. Hence our choice of cell which has its own built-in safety features that exceed UL1642 standards. Together the cells and ITP's proprietary BMS combine to produce a total "battery module" that has an unprecedented level of safety, redundancy and performance. Specific BMS functions:

- ✓ Manages module's state of charge
- ✓ Monitors each cell's voltage (VC1, VC2, ...)
- ✓ Manages module current
- ✓ Disconnects module in over charge
- ✓ Disconnects module in over discharge
- ✓ Performs cell balancing
- ✓ Controls charging and discharging functions within cell specifications
- ✓ Internal fuse built in for last line of defence
- ✓ Communication system that allows:
    - Paralleling of multiple battery modules into a single battery bank
      (i.e. up to 20 modules can be connected in parallel to add capacity as required)
    - Red/green status indicator

- Dry contact alarming
- On-site data logging of critical battery parameters
- Remote monitoring capabilities

The BMS uses quality components in its construction and mean time between failure (MTBF) analysis indicates reliability in excess of 20 years. This, combined with the qualification of the cell electrochemistry (aging profile, failure modes, internal protection and charge/discharge characteristics) has produced a battery with exceptional characteristics ideally suited to meet the needs of telecoms.

**Design Consideration #3: Knowing Your Customer's Needs**

The integration of the cell core and a BMS is a necessary but not sufficient condition to attract the interest of the telecommunications market. Meeting customers' needs in terms of form factor (how the battery fits into and connects up to existing cabinets) is critical and cost is paramount. In order to address these issues, considerable time and effort was devoted to talking to major telecom operators and DC power supply packagers. Their feedback and advice was critical in designing a low-cost lithium ion battery that meets the majority of industry needs. The end result is -48 volt and +24 volt battery systems designed for wireline and wireless application with the following basic specifications:

**Table 1 – Battery Specifications**

| | **-48 Volt** | **+24 Volt** |
|---|---|---|
| **Capacity per Module** | 24, 36 and 50Ah | 48, 72 and 100Ah |
| **Discharge Rate** | Up to C/1 | Up to C/1 |
| **Discharge Current** | 10A (30A capability) | 10A (30A capability) |
| **Cell Balancing** | Yes | Yes |
| **Polarity Protection** | Yes | Yes |
| **Current Charge Limitation** | Yes | Yes |
| **Over Temperature Protection** | Yes | Yes |
| **Over Current Protection** | Yes | Yes |
| **Under Voltage Protection** | Yes | Yes |
| **Alarm and Monitoring** | Dry contact<br>Data logger with alarming<br>Internet (TCP/IP) | Dry contact<br>Data logger with alarming<br>Internet (TCP/IP) |
| **State of Charge Indicators:**<br>LEDS<br>Alarms | <br>Single red/green LED<br>See above | <br>Single red/green LED<br>See above |
| **On/Off Switch** | Not required. BMS controlled | Not required. BMS controlled |
| **Dimensions (mm):**<br>24Ah, 36Ah, 50Ah } -48V; 44Ah, 66Ah, 92Ah } 24V | **Depth / Width / Height**<br>275.0 / 83.4 / 250.0<br>349.3 / 83.4 / 250.0<br>520.7 / 83.4 / 250.0 | **Depth / Width / Height**<br>275.0 / 83.4 / 250.0<br>349.3 / 83.4 / 250.0<br>520.7 / 83.4 / 250.0 |
| **Energy Density:**<br>24Ah, 36Ah, 50Ah } -48V; 44Ah, 66Ah, 92Ah } 24V | **Volume (L) / Wh/Litre**<br>5.8 / 199<br>7.3 / 210<br>10.9 / 220 | **Volume (L) / Wh/Litre**<br>5.8 / 199<br>7.3 / 210<br>10.9 / 220 |
| **Weight:**<br>24Ah, 36Ah, 50Ah } -48V; 44Ah, 66Ah, 92Ah } 24V<br>Note: weight includes BMS electronics, cell core, and battery enclosure. | **Kilograms / Wh/Kg**<br>8.2 / 136<br>11.3 / 139<br>17.3 / 141 | **Kilograms / Wh/Kg**<br>8.2 / 136<br>11.3 / 139<br>17.3 / 141 |

The following graph compares standard VRLA, Ni-Cd and ITP's lithium ion batteries by energy density and weight.

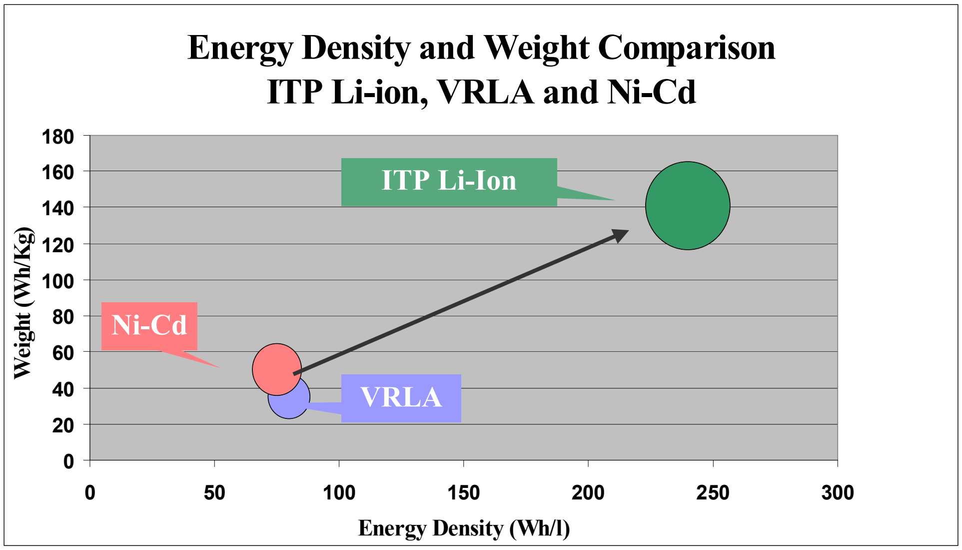



**Figure 3 – Energy Density and Weight Comparisons**

The key attributes of the battery design are as follows:

1. **Form Factor** – The battery dimensions are configured around standard industry rack configurations. The battery maximizes the energy density that can fit into standard 19" and 23" wide racks with rack depths of 12", 15" and 23". Figure 5 shows two 24Ah lithium ion batteries standing vertically in a standard 23" telecom 2U rack configuration. The batteries can also be installed in a horizontal position (Figure 6) depending on the customer's needs.

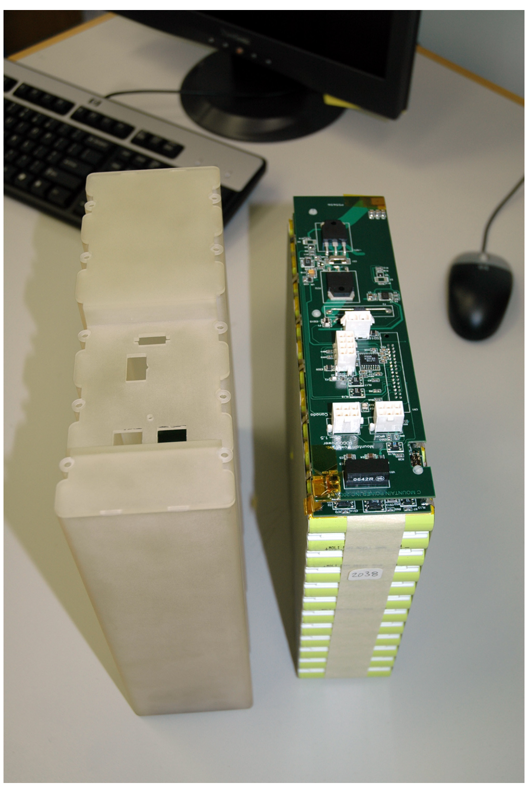
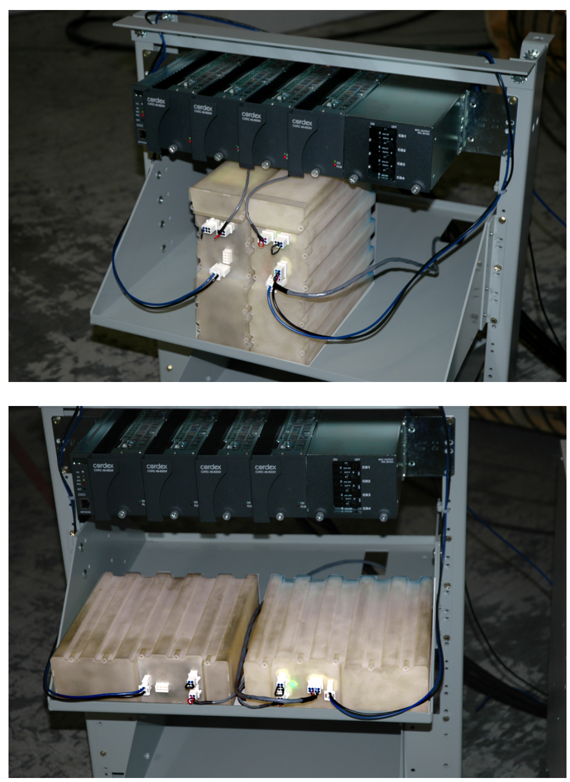


**Figure 4 – Battery Components: Case, Cell Stack and BMS**



**Figures 5/6 – Two 24Ah -48V Lithium Ion Batteries in a Standard 23" wide and deep Telecom Rack**

2. **Installation flexibility** – The batteries are a modular design meaning that up to 20 modules can be connected in parallel to form a string with capacities matching a customer's needs. Multiple battery strings can be installed as required. In addition, since the batteries are dry with no spillage concerns, the batteries can be installed in whatever configuration the customer needs. For example, in a standard 23" wide and deep rack system, six 50Ah battery modules can be installed upright to provide up to 300Ah of capacity. Further, if the customer requires a 2U shelf configuration, two 50Ah batteries can be laid down to provide 100Ah of capacity. Another design consideration was to utilize an industry accepted power connector and cabling, flexible enough to allow easy installation.

3. **Compatibility in existing and new DC power plant systems** – Telecom companies have a diverse inventory of new and old rectifier systems each with its own charging and protection characteristics. One issue that was identified was the possibility of the network being compromised when AC power came back in service and, due to the battery's low impedance, excessive current could be directed to the batteries thereby dropping the network voltage below acceptable levels. While in most cases this was not an issue, we addressed this potential problem by modifying the BMS to have a more VRLA-type charge characteristic. .

4. **Certification** – The NEBS Level 1 and 3 standards developed by Telcordia are, in most cases, the de facto standards required by the telecom industry for batteries used in critical networks. Accreditation by a certified lab, such as Underwriters Laboratory (UL), is an essential step in gaining a customer's confidence in any battery product.

**Design Consideration #4: Cost**

Is lithium-based battery technology the lowest cost solution for the telecom industry? That depends on the application and the site conditions where the battery will be deployed. In air-conditioned central offices, where space is not an issue, it is unlikely that the business case for lithium batteries will be attractive when compared to flooded lead acid and VRLA technologies. However, in many environments and applications, lithium battery technology can demonstrate a very compelling business case. Some applications that we have identified include:

- Outdoor cabinet installation where more space is needed for revenue generating equipment,
- In environments where a more heat-tolerant lithium battery would reduce long-term battery maintenance and replacement costs,
- An installation where a higher degree of system reliability is required, and
- In central and satellite offices where distributed DC power plant systems are being considered. In this case the driving force for the telecom is the total capital cost of new plant which includes existing plant modifications, equipment replacement and the requirement for expensive large copper conductoring throughout the customer's premise.

In order to understand the business case for lithium batteries, we put together a simple economic model to determine the life cycle cost of a VRLA compared to a lithium ion battery installation in an outdoor cabinet installation. The assumptions in this analysis used labour rates and maintenance hours presented in a previous Battcom paper [(3)].

Methodology

1. Construct a simple economic model using net present value analysis.
2. Incorporate all life cycle costs including initial capital costs, maintenance costs, battery replacement and disposal costs.
3. Compare the total discounted costs of the VRLA and lithium ion battery technologies on an annualized $/kW basis.

Assumptions/Parameters:

- Discount rate set at 10%
- Labour rates, including equipment (trucks and tools), charged out at $80/hour[(3)]
- 10 hours of direct labour required annually to maintain VRLA batteries[(3)] ;
  zero maintenance is required for lithium batteries
- VRLA batteries last 3-5 years; lithium batteries last 10 years.

The results of the analysis are summarized in the following graph. The key point is that the 18650 lithium ion battery cost far less on a $/kW annualized basis. To understand the magnitude of the savings multiply the amount of installed battery capacity at similar sites by the difference in the annualized $/kW savings (VRLA $/kW less lithium-based $/kW). Using the example below and assuming an average of 100Ah of capacity installed at 20,000 similar sites the annualized savings total $240 million. To put it another way, the additional capital cost of a lithium-based battery system can be paid out in less than one year.

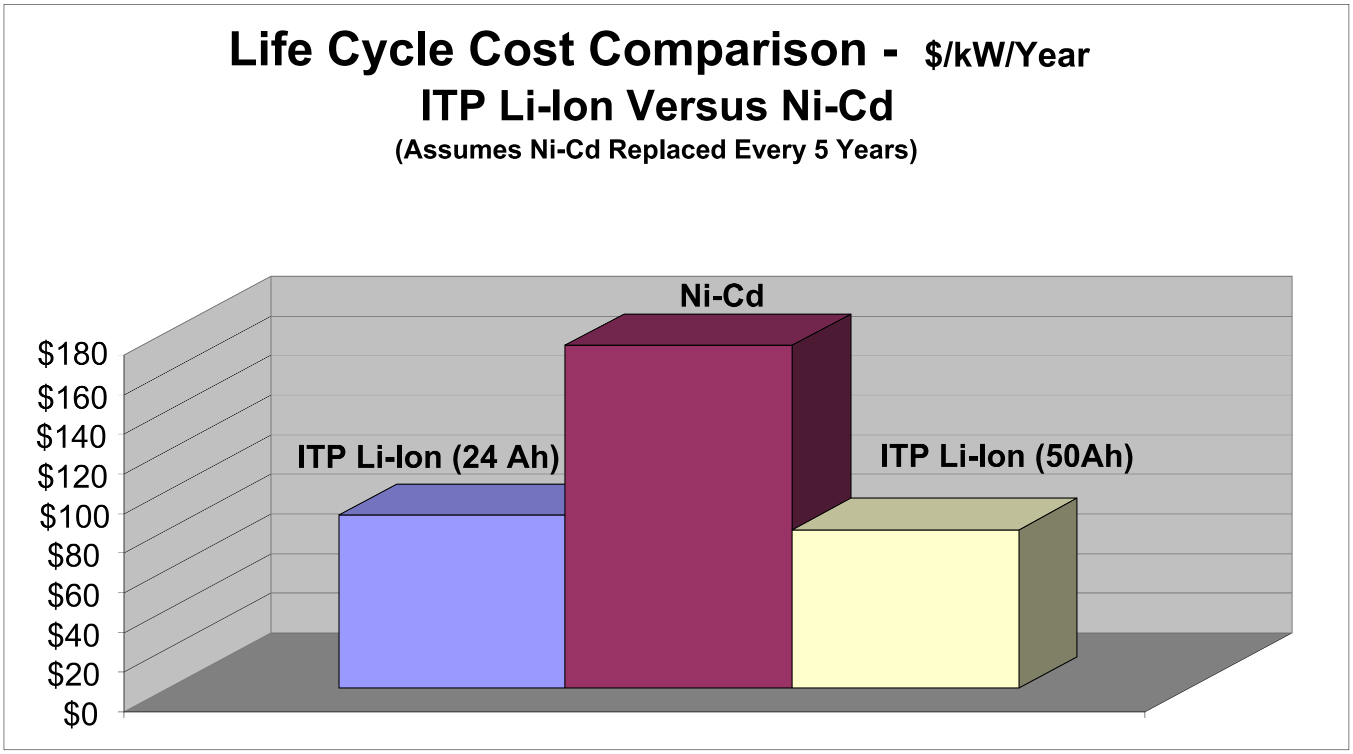



**Figure 7 – Life Cycle Cost Analysis: Lithium Ion versus VRLA**

## CONCLUSION

Combining proven lithium ion cell chemistry with a state-of-the-art battery management system and paying close attention to customers' needs has produced a next generation lithium ion battery for distributed power applications in the telecom sector.

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(3) Fountain, Bruce, "Battery Maintenance and Monitoring – What's Real or Not?", Proceedings, Battcon 2004