# GAIA Li-Ion Batteries: Evolution or Revolution?

GAIA Europe
Company Secretary
Tim Schäfer
Akkumulatorenwerke GmbH, Nordhausen, Germany
Lithium Technology Corporation, Plymouth Meeting, PA, USA

November 2005

# Overview



Proprietary Information, November,2005

Lithium Technology Corporation

GAIA Advanced Lithium Battery Systems

LTC Lithium Technology Corporation

GAIA Advanced Lithium Battery Systems

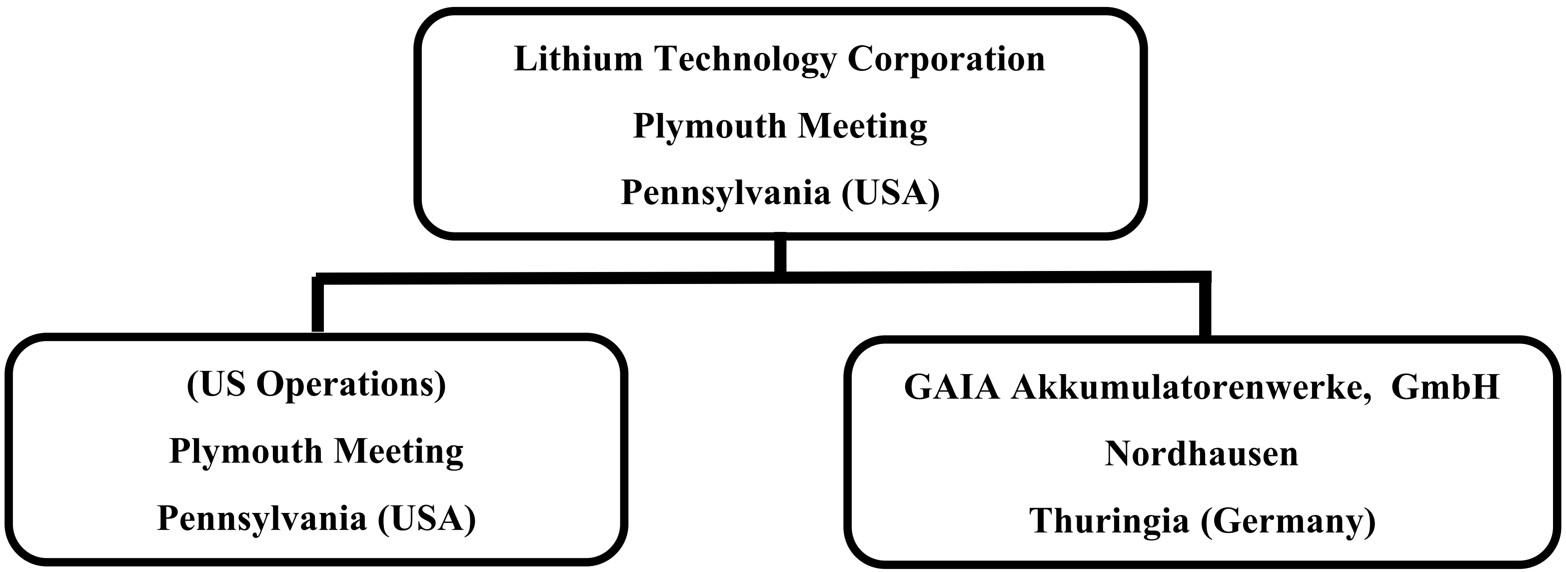
# History

- April 1996 Founding of GAIA
- 1997 Proprietary extrusion process
- 1998 Arch Hill, a Dutch venture capital company, acquires majority share of GAIA
- 1999 Installation of three pilot extrusion lines
- 2000 Refinement of battery production facilities
- 2002 Merger of GAIA and LTC
- 2003 Market entry with large format Lithium ion **cells**
- 2005 Market entry with Lithium ion **batteries**

Proprietary Information, November,2005

# Corporate Structure

- Lithium Technology Corporation is a Public US Corporation traded on the OTC Bulletin Board (LTHU.OB)
- LTC and GAIA were merged in 2002 combining two synergistic technologies




Proprietary Information, November,2005

# Facilities


## US Operations
**(LTC** - Plymouth Meeting)

- Corporate Headquarters
- US Government/Military Development Contracts
- R & D and cooperative programs with US raw material suppliers
- US Sales
- Battery design and assembly using GAIA cells
- Limited contract production of specialty **flat** cells


## European Operations
**(GAIA -** Nordhausen**)**

- European Development Contracts
- R & D and cooperative programs with EU raw material suppliers
- European Sales
- Commercial Production of **cylindrical** cells
- Battery design and assembly

Proprietary Information, November,2005

# Current Operations

## Small Production/Large Pilot Scale Operation

- 57 Employees (17 in US, 40 in Germany)
- FACILITIES
  - 176,000 $ft^2$ facility in Nordhausen, Germany
  - 13,000 $ft^2$ facility in Plymouth Meeting, PA, USA

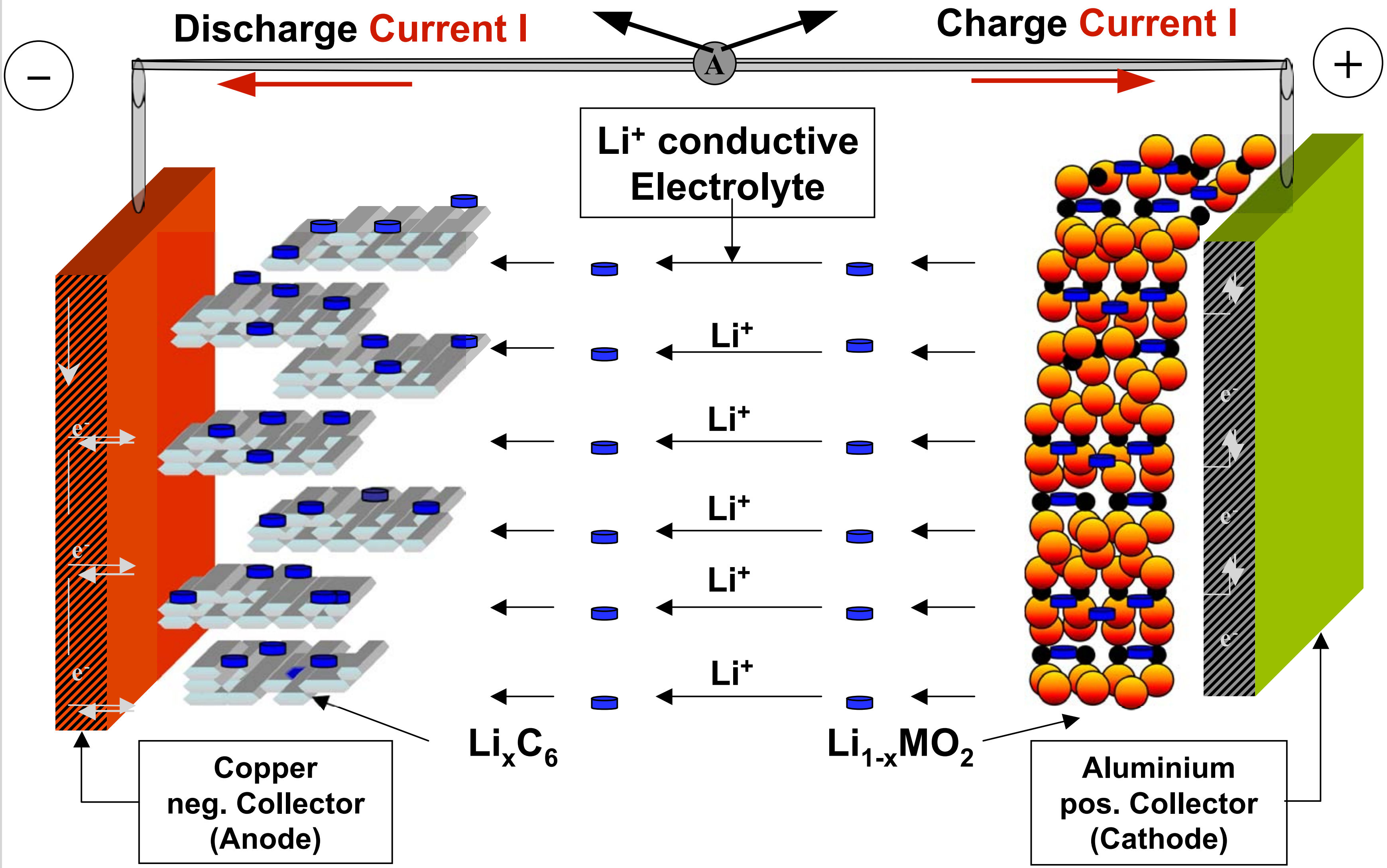
- PRODUCTS:
  - Custom engineered batteries
  - Development contracts
  - Cylindrical and prismatic Lithium-Ion cells
    - from 5 Ah to 120 Ah

LTC Lithium Technology Corporation

GAIA Advanced Lithium Battery Systems

# GAIA Technology

# Principle of Lithium Ion Batteries




Proprietary Information, November,2005

LTC Lithium Technology Corporation

GAIA Advanced Lithium Battery Systems

# Technological Advantages of Lithium-Ion over other Chemistries

| | Lead Acid | NiMH | Li_Ion |
|---|---|---|---|
| **Energy per Weight** | 1 | 2 x | 3 x |
| **Energy per Volume** | 1 | 1.5 x | 2 x |
| **Power per Weight** | 1 | 5 to 10 x | 5 to 15 x |
| **Power per Volume** | 1 | 3 to 6 x | 3 to 10 x |
| **Fast Charge** | Poor | Good | Very Good |
| **Heat Generation** | High | Low | Very Low |
| **Operational Temperature Range** | Narrow | Wide | Very Wide |
| **Battery Complexity (Number of Cells)** | Medium (2V per cell) | High (1.2V per cell) | Low (3.6V per cell) |

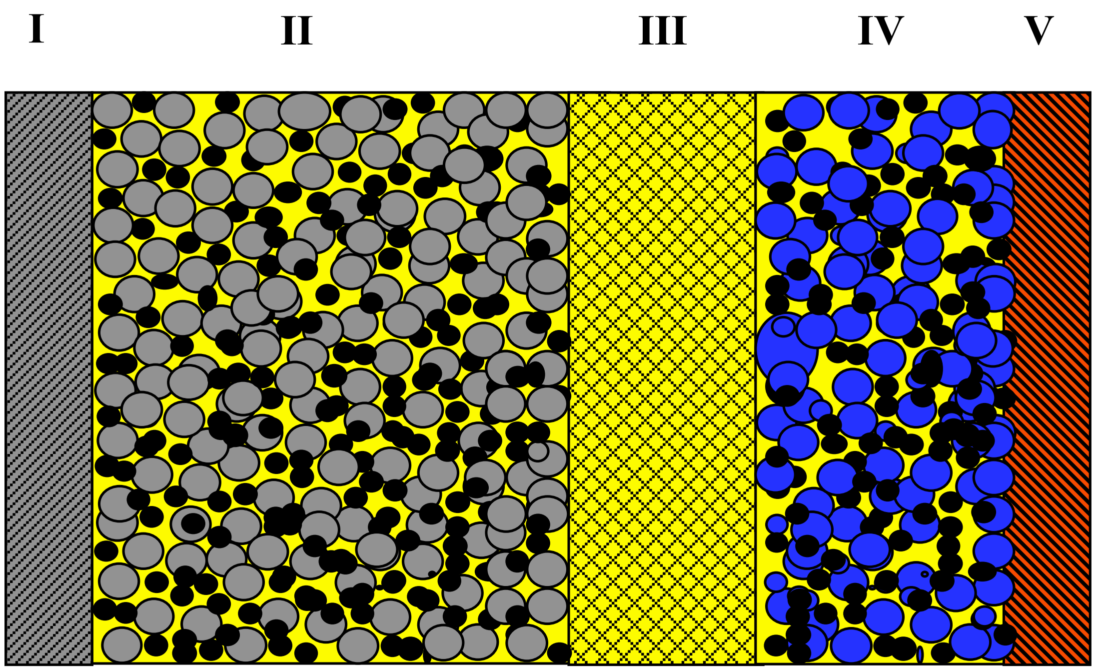
Proprietary Information, November,2005

# LTC Differentiators

- **Proprietary cell design IP**
  - Low internal resistance allows for high power output and rapid charging with limited heat generation
- **Proprietary manufacturing process**
  - Lower cost extrusion and assembly allows scalability and opportunity for high gross margins
  - Environmentally friendly (no solvents)
- **Patents**
  - Issued 33
  - Applications Pending 42

Proprietary Information, November,2005

# Li-Ion Technology




I: Al-Collector (18-25 µm)

II: Positive Electrode (40-200 µm)

III: Separator (16 – 35 µm)

IV: Negative Electrode (30-150 µm)

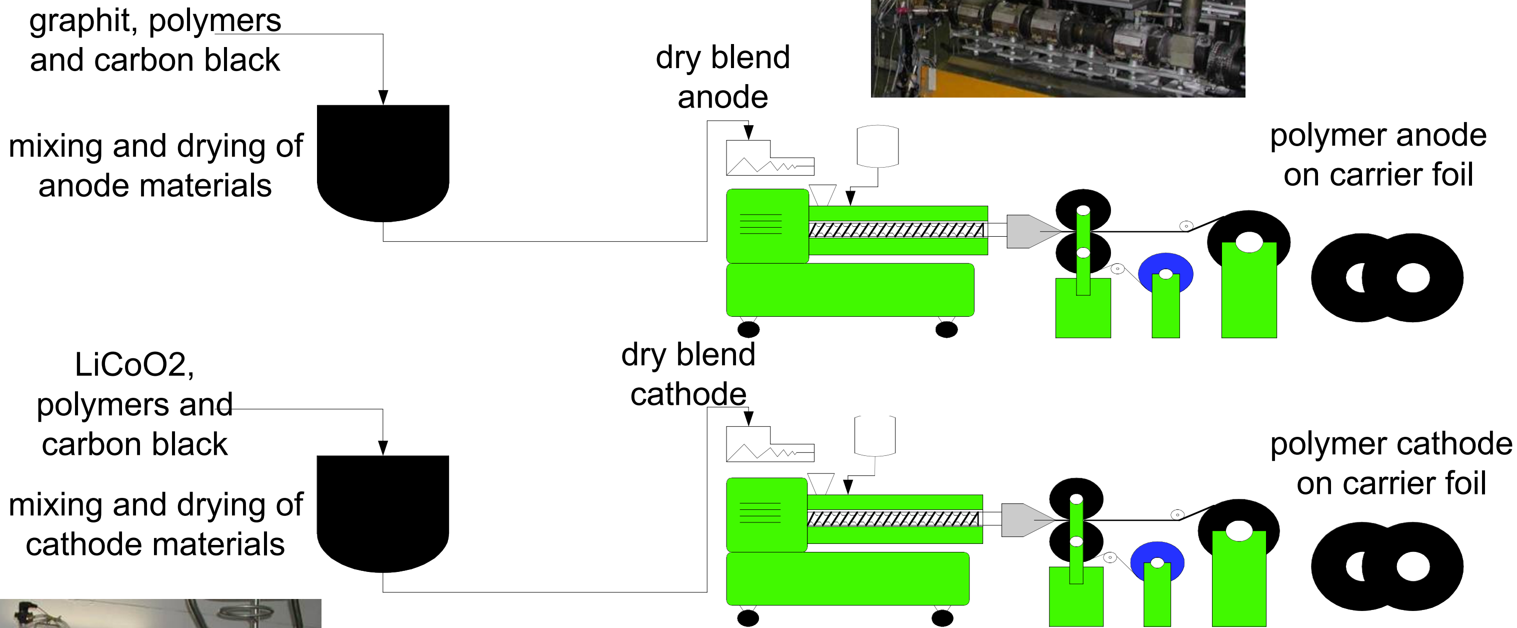
V: Cu-Collector (12-20 µm)

Proprietary Information, November,2005

LTC Lithium
Technology Corporation

GAIA
Advanced Lithium Battery Systems

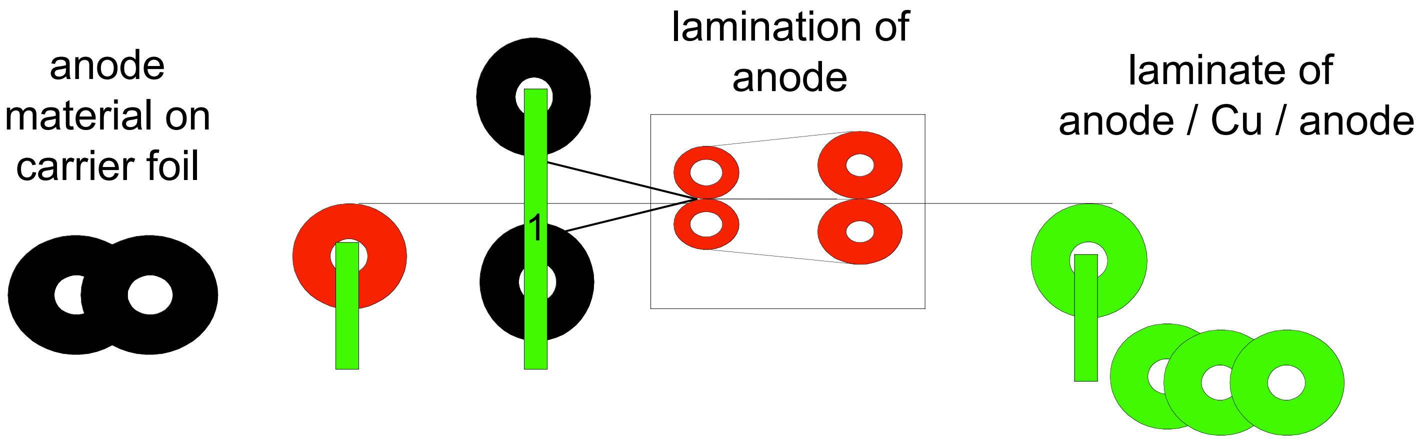
# Process - Extrusion

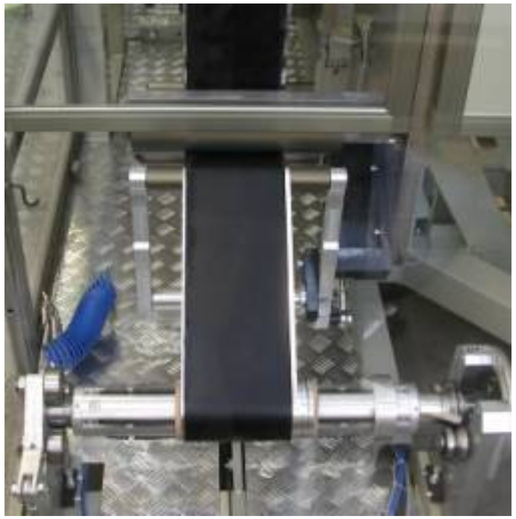



- ☑ No emission of solvents
- ☑ Safe and environmental
- ☑ No ex-proof installation
- ☑ Cost-effective
- ☑ Co-extrusion of polymer blends

Proprietary Information, November, 2005

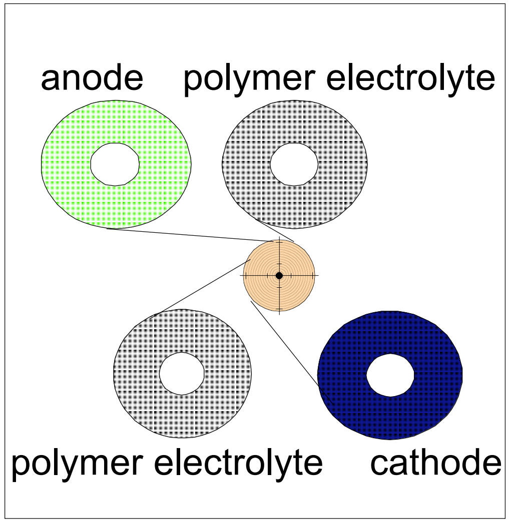
# Process - Lamination

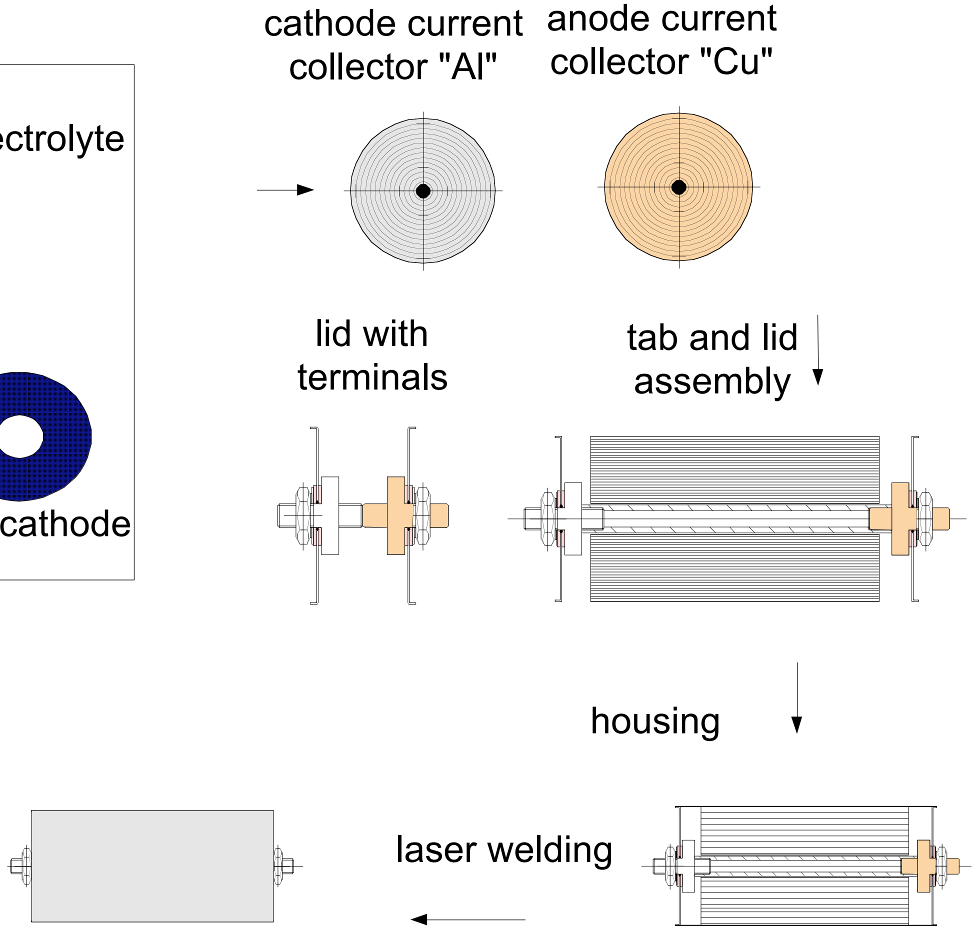


# Processing Technology - Winding & Assembling

cell winding machine



LTC Lithium Technology Corporation

GAIA Advanced Lithium Battery Systems

# GAIA Product Portfolio

LTC Lithium Technology Corporation

GAIA Advanced Lithium Battery Systems

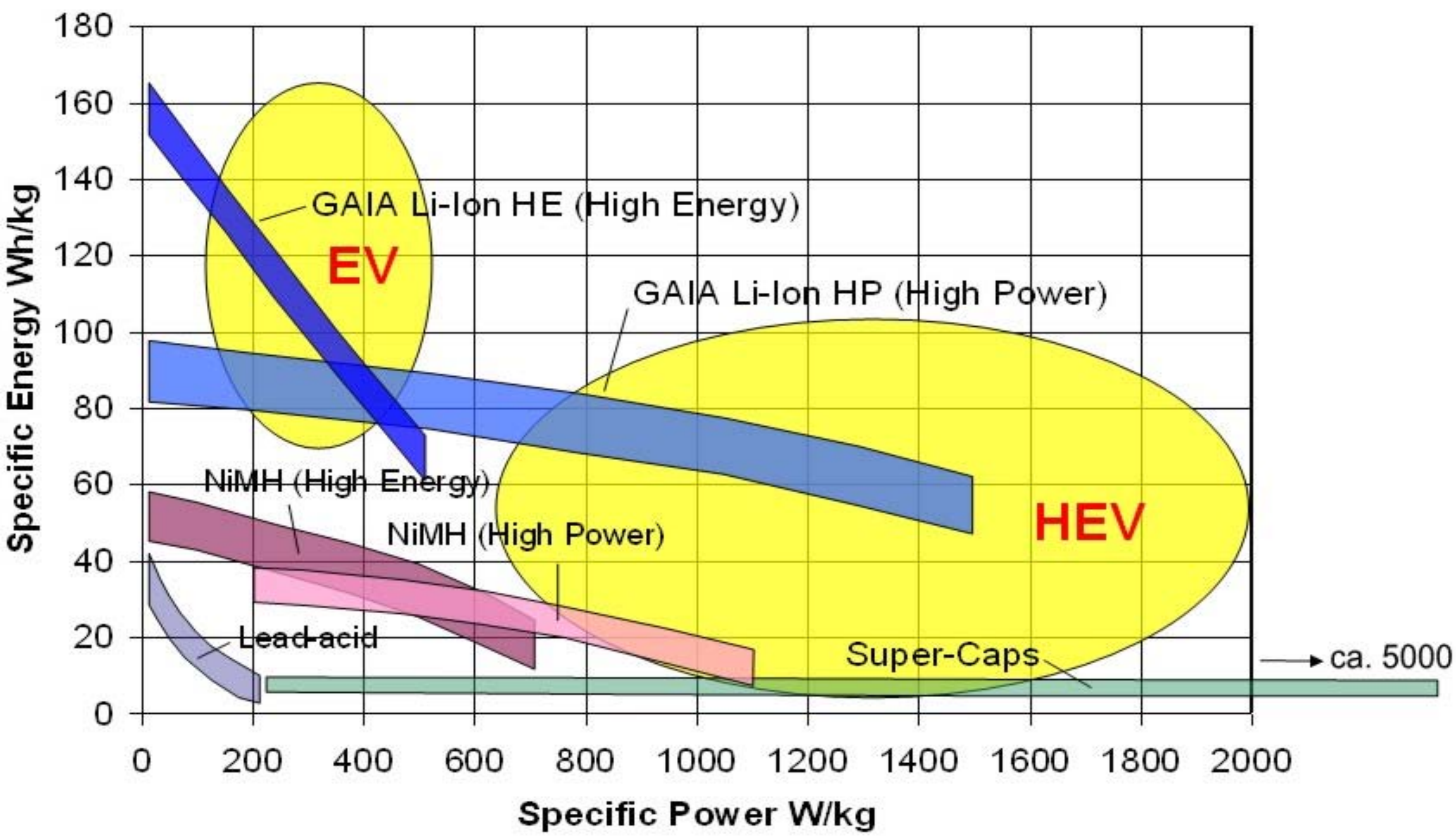
## GAIA Product Portfolio

- Present cylindrical cells range in capacity from 5 Ah to 60 Ah

- GAIA offers two basic types of products taylored to different applications
  - The HE product series is optimized towards high energy content with moderate rate capability (continuous discharge up to 2C)
  - The HP and UHP series are designed to deliver maximum power (continuous discharge up to 10C)

- GAIA has developed battery packs of up to 600V to customer specifications

# Battery Systems Comparison - Ragone Plot



LTC Lithium Technology Corporation

GAIA Advanced Lithium Battery Systems

# Large, High Power Engineered Lithium Ion Is LTC's Core Expertise

- GAIA cells offer the highest power of any commercial lithium ion cell in the western hemisphere* (most amperes or watts per kilogram)
  - GAIA UHP product achieves 2400 W/kg (pulse)
- GAIA cells are the largest lithium ion cells produced in the western hemisphere (most energy capacity - watt-hours or amp hours)
  - GAIA HE-602050 has 60 Ah or 216 Wh corresponding to 150 Wh/kg
  - 120 Ah cell is in development
- LTC specializes in working with the customer to engineer solutions using standardized cells in customized configurations
  - Custom engineered battery packs including electronic battery management systems

*** US and EU companies have an advantage selling the western hemisphere being domestic suppliers and it is unrealistic for US and EU companies to sell into Asia.**

Proprietary Information, November,2005

LTC Lithium Technology Corporation

GAIA Advanced Lithium Battery Systems

# GAIA Markets

# Markets with Projected Growth in Advanced Batteries

### Military/National Security

Applications require flexibility in design, wide ranges of power output, broad operating temperatures, low weight and thousands of recharge cycles. Performance is more important than price. Market need is growing quickly. Development funding is available.

### Transportation

Applications require rapid charging rates and long life in safe, durable high power storage for HEV, EV and fuel cell powered vehicles. Military, heavy duty and niche vehicle OEMs are early adopters. Immediate niches exist.

### Stationary Power

Growing dependence on electrical power worldwide drives the demand for high quality high-reliability power for telecommunications, computers, mission critical applications, remote mobile and renewable power applications. Very large potential market.

## Military/ National Security Market

**The US and its allies are changing the military landscape. The trend is to many small, rapidly deployed units using extensive power-intensive electronics. Applications already exist in this market and continue to grow rapidly.**

- Unmanned reconnaissance and combat support systems
  -- airborne, ground, underwater
- Satellite surveillance and communications systems
- Remotely controlled surveillance, detection and demolition robots
- Manned combat support vehicles -- land-based and underwater
- “Silent Watch” (stealth operations on battery power only)
- Night goggles, communications equipment, GPS, computers, handheld spotlights, etc.

Proprietary Information, November,2005

# Transportation Market

**American and European auto manufacturers are now taking the Japanese HEV effort seriously**

- Existing applications (lithium ion SLI [starting, lighting & ignition] batteries)
  - Motorcycles
  - Racing cars
  - Certain very high end automobiles – dual battery systems
- Developing applications / trends (HEVs,EVs)
  - Wheelchairs
  - Taxies
  - City delivery vans
  - All terrain vehicles (ATVs) & snowmobiles for national parks
  - Professional lawn and garden
  - Neighborhood electric vehicles (NEVs)

Proprietary Information, November,2005

LTC Lithium Technology Corporation

GAIA Advanced Lithium Battery Systems

# Stationary Power Market

**Growing dependence on digital devices for mission critical applications drives demand for uninterrupted (distributed) power and backup power. Life cycle value of lithium ion over lead acid is a key market advantage.**

- Existing applications
  - Telecom: lower cost of cooling/heating the facilities; less maintenance; remote monitoring
  - Solar: less maintenance, longer battery life
  - UPS: space/weight savings, higher reliability, less maintenance, longer life and lower life cycle cost
- Developing applications / trends
  - New wireless network installations with lower cost infrastructure
  - Heightened awareness of need for backup systems following storms and blackouts
  - Wind and solar power

Proprietary Information, November,2005

# Rechargeable Battery Market Size for National Security, Transportation, and Stationary Power

| | 2003 | | | | | | 2011 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Conventional | | Advanced | | Total | | Conventional | | Advanced | | Total | |
| Transportation | $ | 8,000 | $ | 50 | $ | 8,050 | $ | 7,400 | $ | 1,400 | $ | 8,800 |
| National Security | $ | 2,000 | $ | 200 | $ | 2,200 | $ | 2,200 | $ | 500 | $ | 2,700 |
| Stationary Power | $ | 5,000 | $ | 50 | $ | 5,050 | $ | 6,500 | $ | 250 | $ | 6,750 |
| Total | $ | 15,000 | $ | 300 | $ | 15,300 | $ | 16,100 | $ | 2,150 | $ | 18,250 |

**Conventional: Lead-Acid**
**Advanced: Li-Ion, NiCd, NiMH**

***Continuous growth of the advanced market over 700% in 8 years***
***Within the advanced market, lithium ion will grow faster than competing chemistries***

Sources: Frost & Sullivan, LTC investigations

# Partnerships that have Developed as a Result of Our Demonstrated Capabilities

- GAIA GmbH has entered into a contract with a European submarine manufacturer to jointly develop and supply very large lithium ion cells for underwater non-nuclear submarine propulsion
- LTC has signed a contract with a major US battery company to develop and supply rack-mounted backup power supplies
- LTC is discussing a joint venture arrangement with a small European EV/HEV manufacturer to supply batteries for inclusion in the drive train for HEVs/EVs

Proprietary Information, November,2005

LTC Lithium Technology Corporation

GAIA Advanced Lithium Battery Systems

# HP-341450 Cell for Hybrid Electrical Vehicle Battery

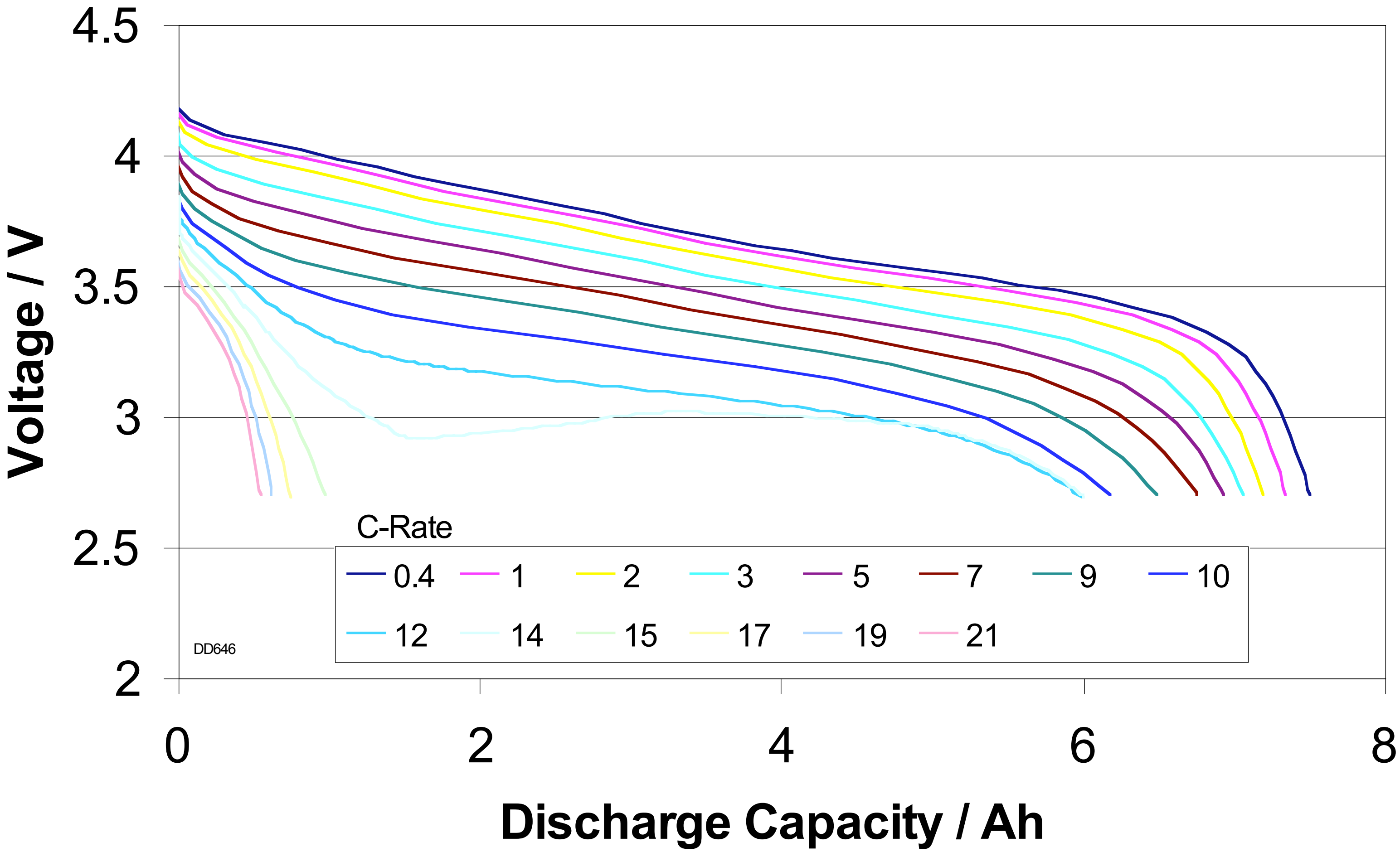
# Cells for HEV Batteries

**DD cell UHP341450 "7.5Ah"**

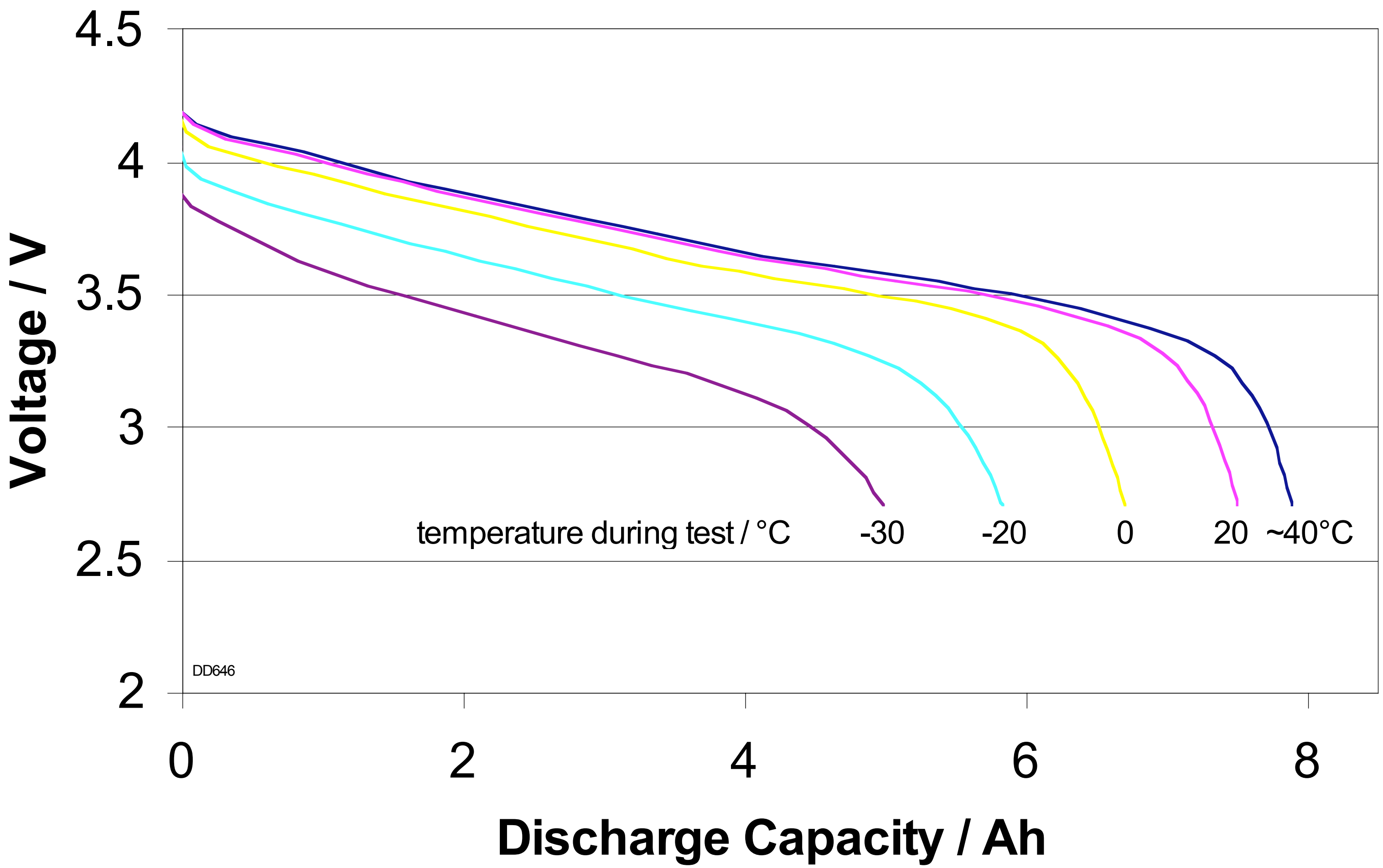
| | |
|---|---|
| Diameter | 34 mm |
| Height (w/o terminals) | 145 mm |
| Weight | 320 g |
| Volume (w/o terminals) | 132 $cm^3$ |
| Case material | Stainless steel |


Proprietary Information, November,2005

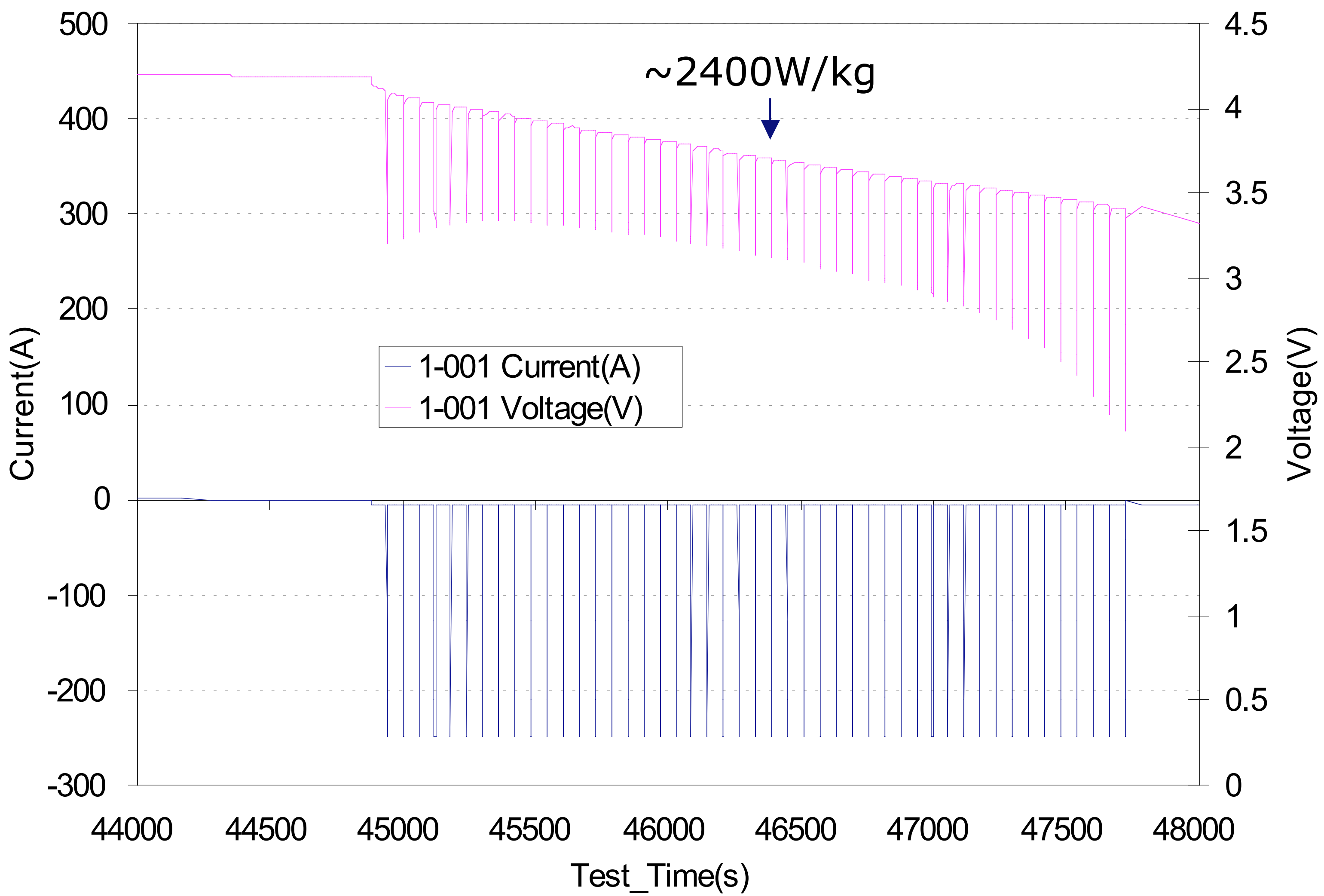
# GAIA 7.5Ah DD HEV Cells
# Discharge Curves: 20°C at Different Rates



# Discharge Curves: C/2 at Different Temperatures

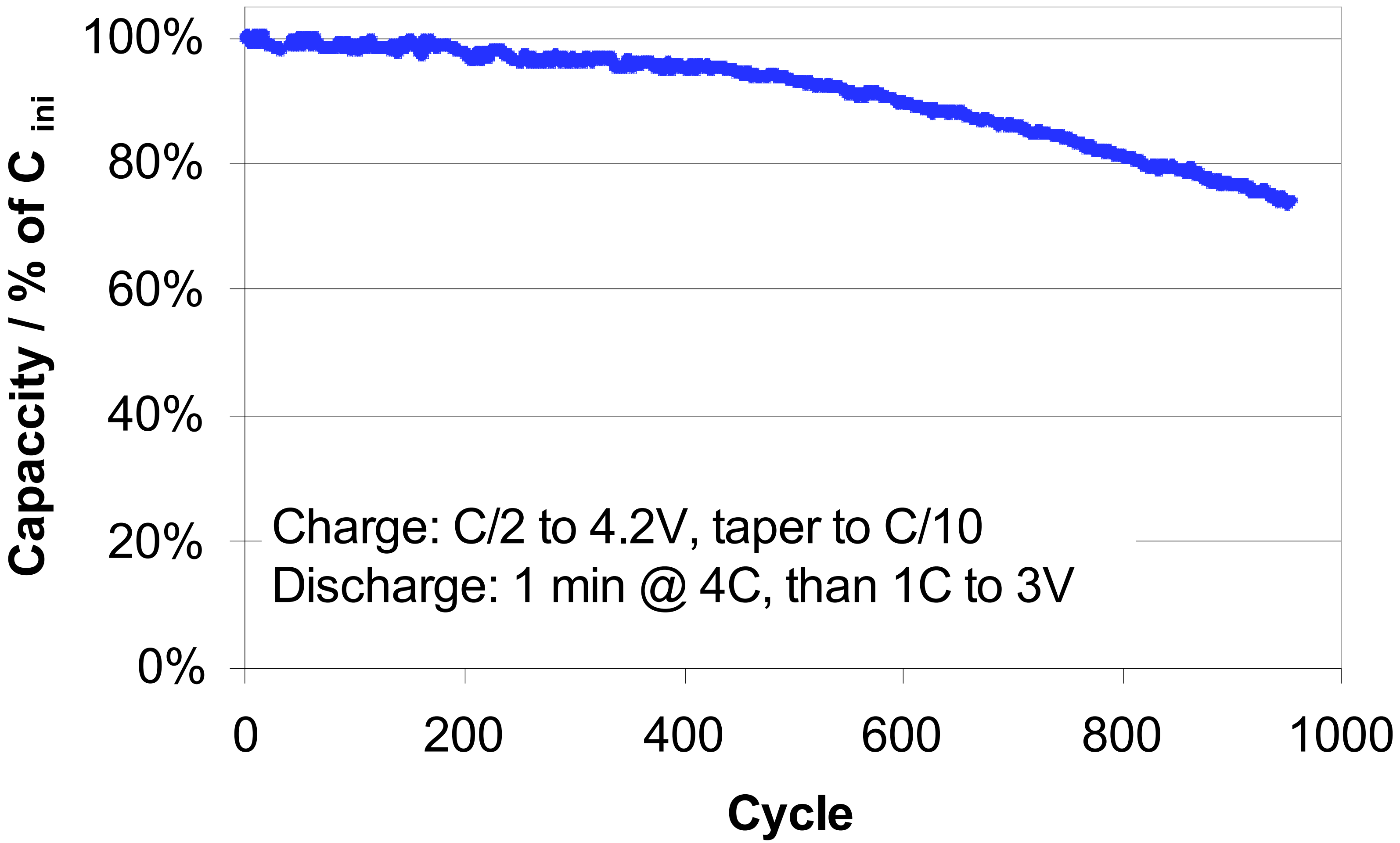


# HP341450: 250A Pulse for 500ms



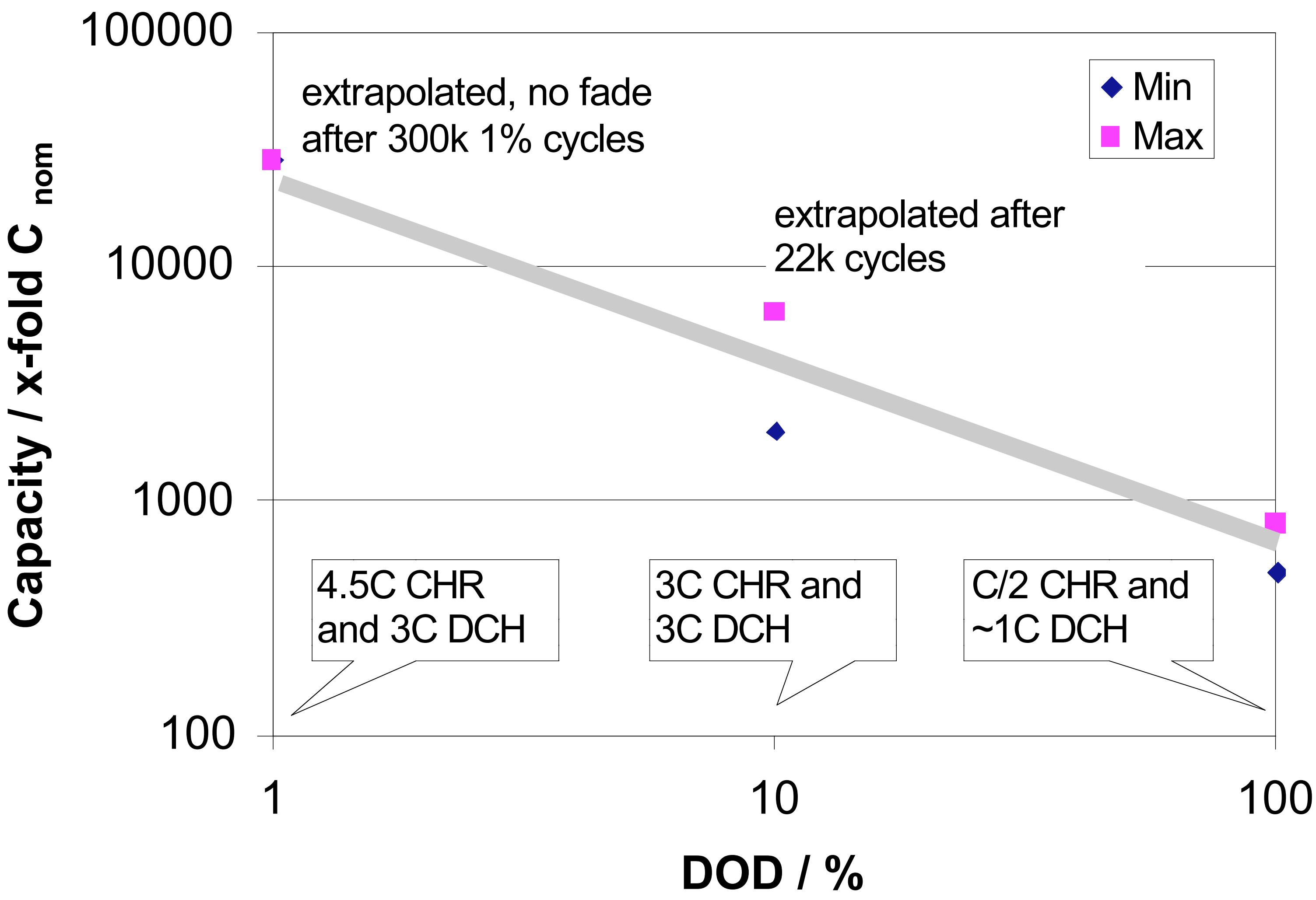

Proprietary Information, November,2005

# Cycle Performance at 100% DoD

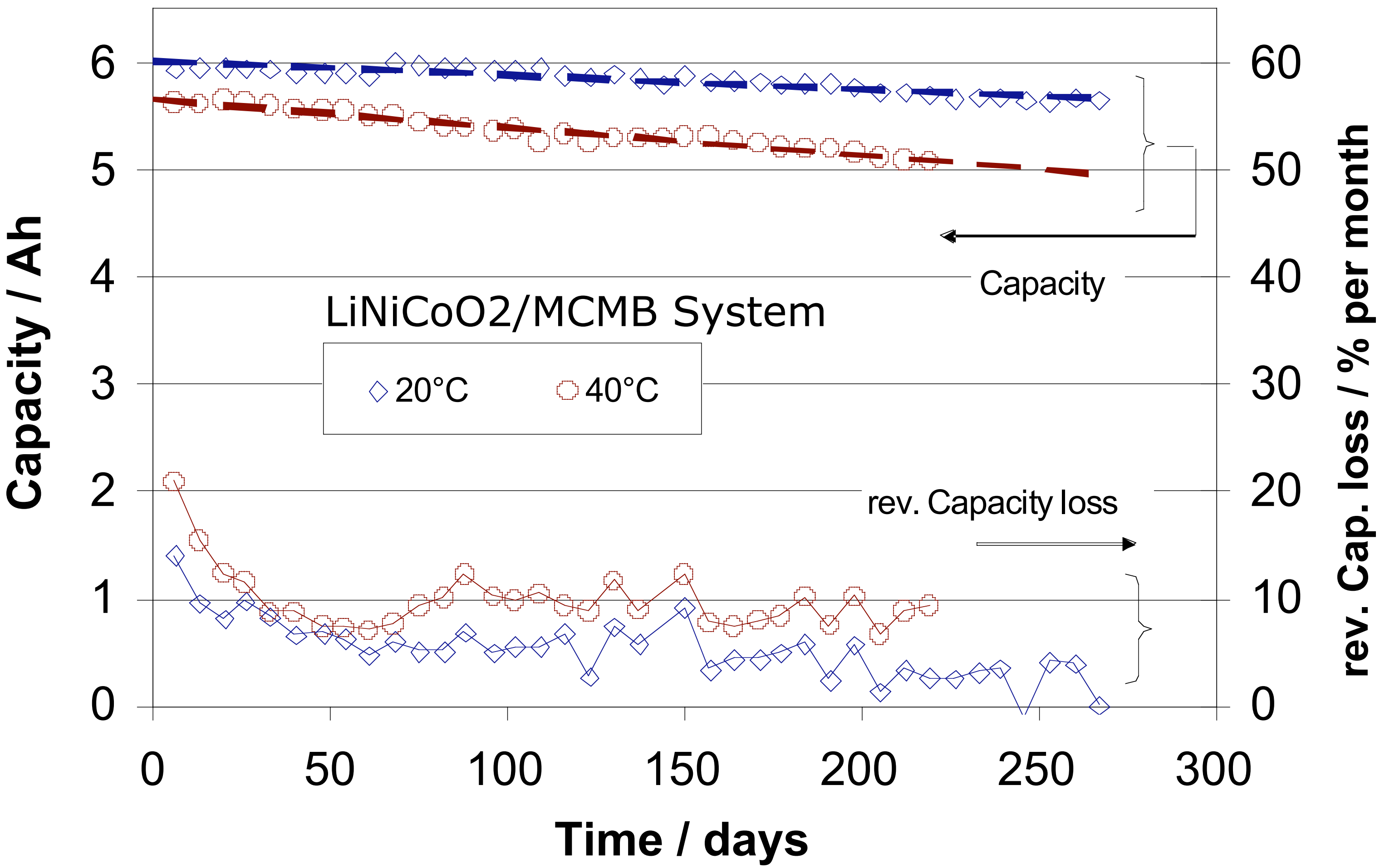



Proprietary Information, November,2005

# Cycling Experiments (Summary)



# Calendar Life & Self Discharge




Proprietary Information, November,2005

Lithium Technology Corporation

GAIA Advanced Lithium Battery Systems

# Safety Tests on Cell Level

| | | |
|---|---|---|
| **Electrical Tests** | | |
| Short Circuit at RT | temperature rise | ✓ |
| Short Circuit at 60°C* | | ✓ |
| Abnormal Charge | sparks and smoke | ** |
| Abnormal Discharge | | ✓ |
| **Mechanical Tests** | | |
| Crush | small deformation | ✓ |
| Impact | small dent | ✓ |
| Shock* | de-contacting | ✓ |
| Vibration | | ✓ |
| Fall | small dents | ✓ |
| **Environmental Tests** | | |
| Temperature Cycling | | ✓ |
| Heating* | | ✓ |
| Altitude Simulation | | ✓ |

**According to UL1642 and ADR**

Summary of tests on 7.5 and 60Ah cells

*small variation to the standard

** not a requirement on the cell level

Proprietary Information, November,2005

LTC Lithium Technology Corporation

GAIA Advanced Lithium Battery Systems

# Battery Management System

# Justification for the Battery Management System

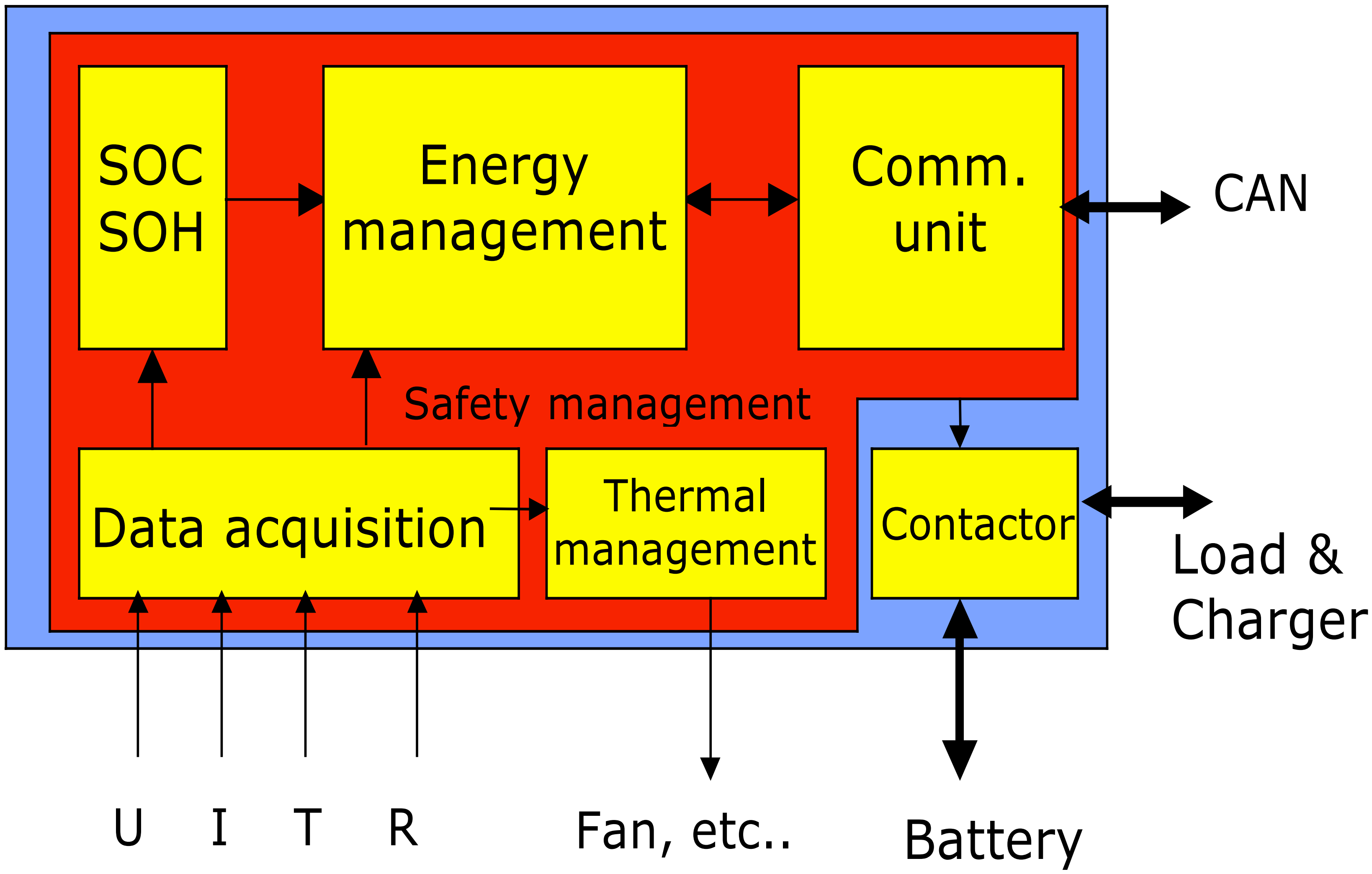
- The recommended battery charging method is IU-charging (const. current, const. voltage)
- But:
  - In a serial string the charger can not control individual cell voltages.
  - Li-Ion cells do not tolerate overcharging with "elevated" voltages for balancing the cells (e.g. "float or boost charging")
  - Abuse or operation out of range could result in safety issues by thermal runaway

⇩

- Li-Ion Batteries require a battery management system (BMS) or an electronic protection circuit

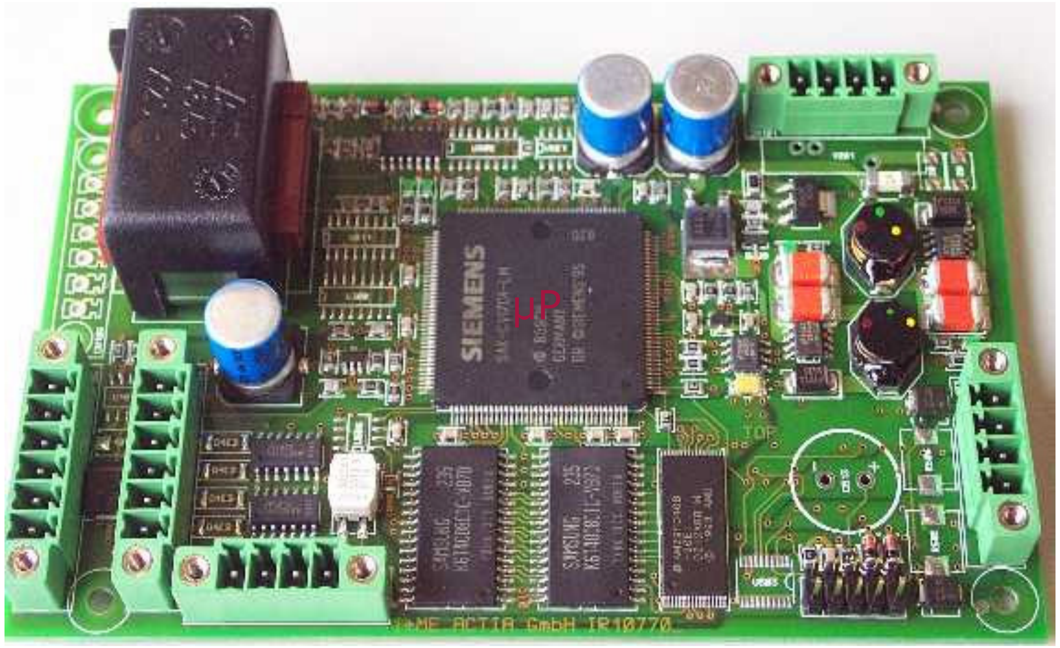
Proprietary Information, November,2005

# Block Diagram of BMS



# Example of 10S BMS Hardware

Current sensor | Master | Slave (10S) | to cells





MUX

Sensors & main switch

130 cm²

CAN interface

RS232 for flashing Master

Optically decoupled RS485 bus

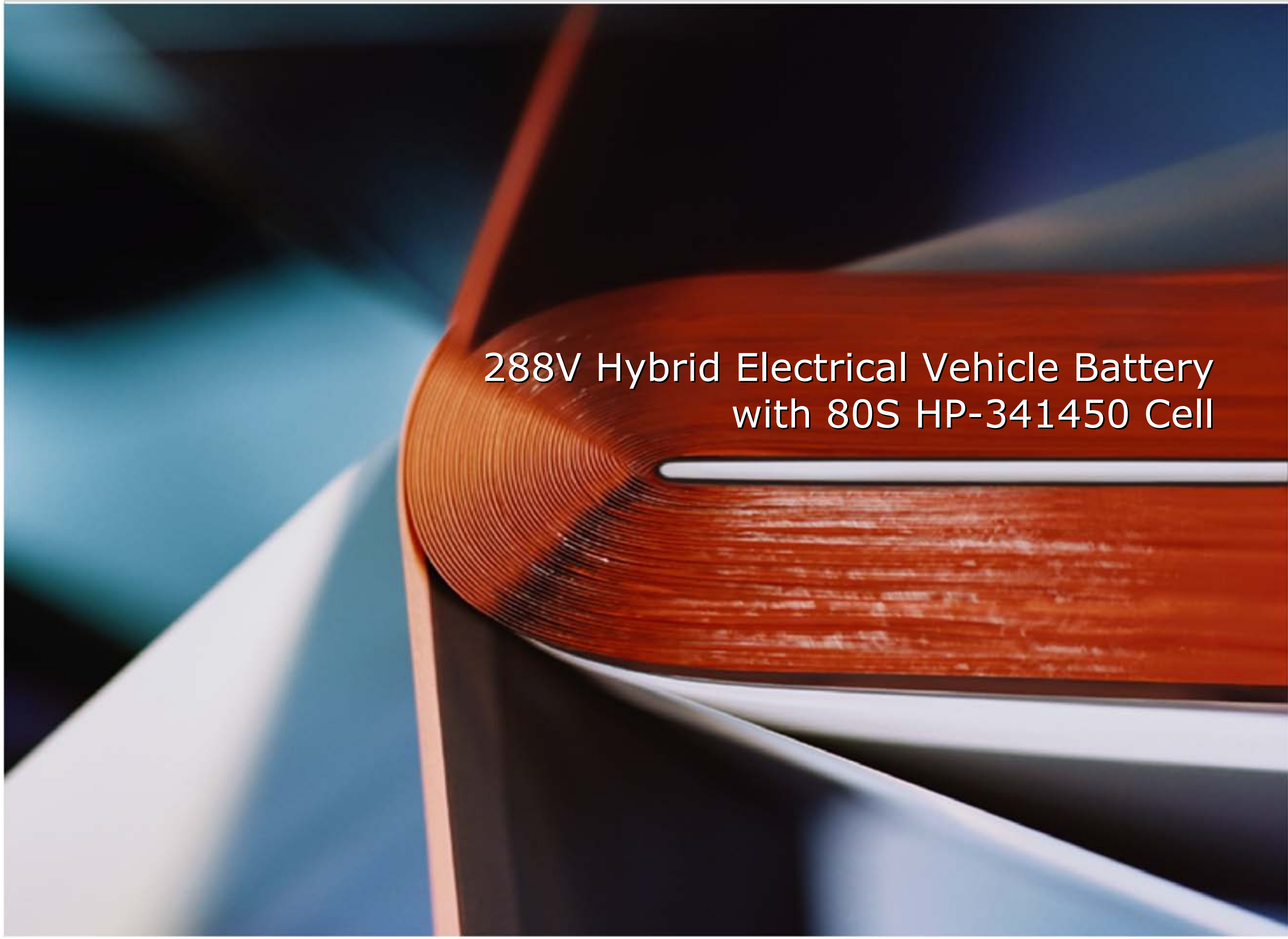
40 cm²

| | | | |
|---|---|---|---|
| | [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] | [redacted] |

Proprietary Information, November,2005

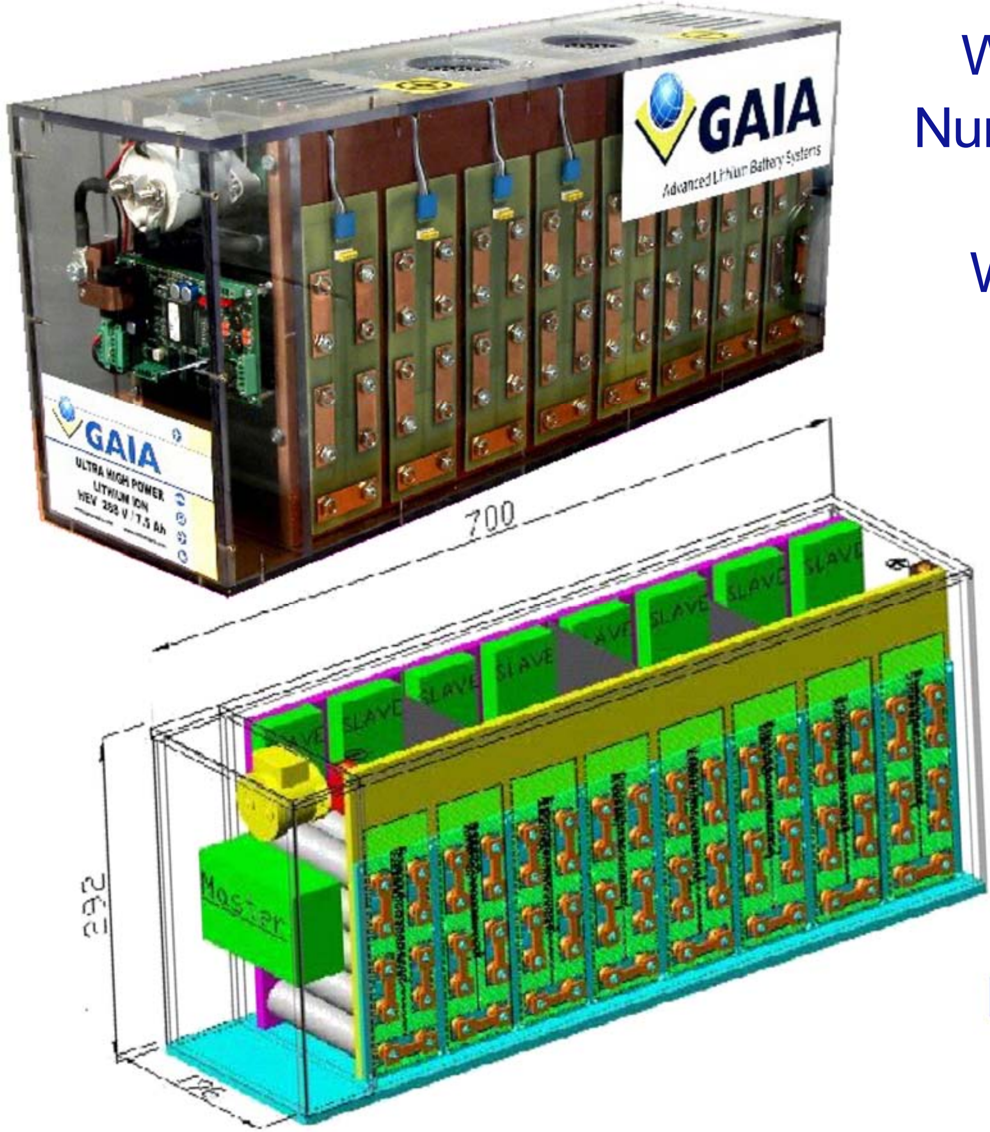
LTC Lithium Technology Corporation

GAIA Advanced Lithium Battery Systems



# 288V Hybrid Electrical Vehicle Battery with 80S HP-341450 Cell

# 288V HEV Battery with 2kWh

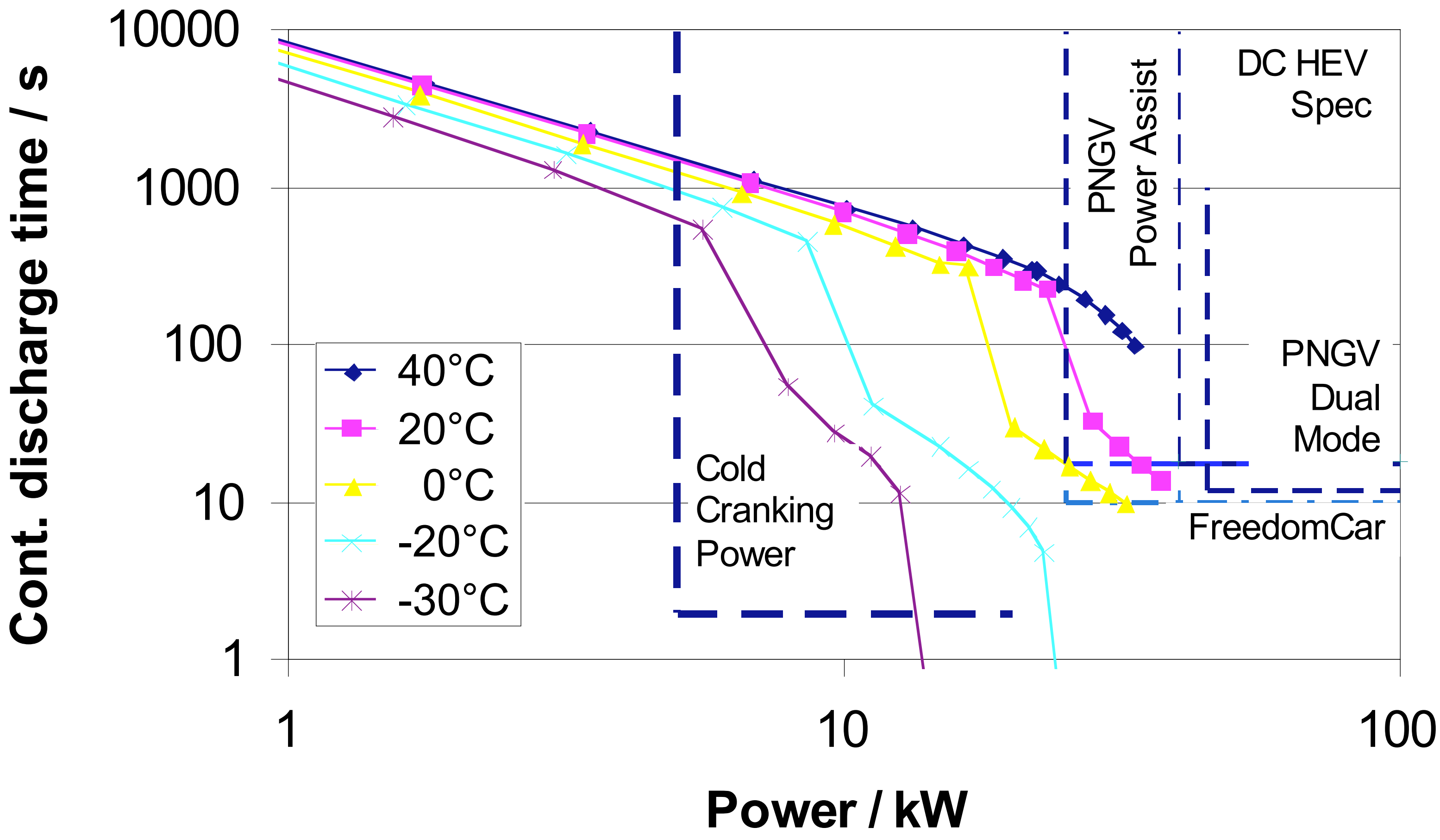



| | |
|---|---|
| Weight of cell | 0.32 kg |
| Number of cells | 80 |
| Packaging | 30 % |
| Weight today | 42 kg |
| **Weight** | **33 kg** |
| Length | 700 mm |
| Width | 292 mm |
| Height | 195 mm |
| **Volume** | **40 L** |
| **Power (18s)** | **25 kW** |

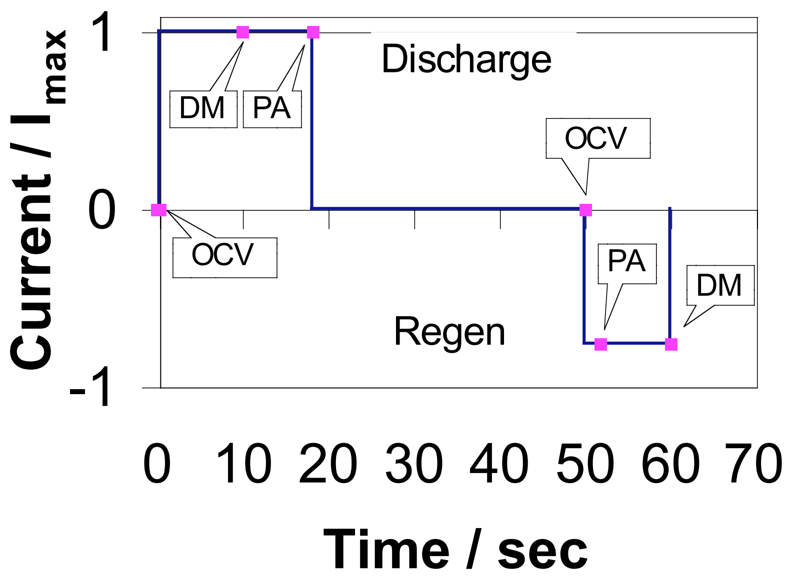
Proprietary Information, November,2005

# "Peukert" Plot of a Simulated HEV Battery

**of 288V HEV battery**
**Power calculated with BSF=80**



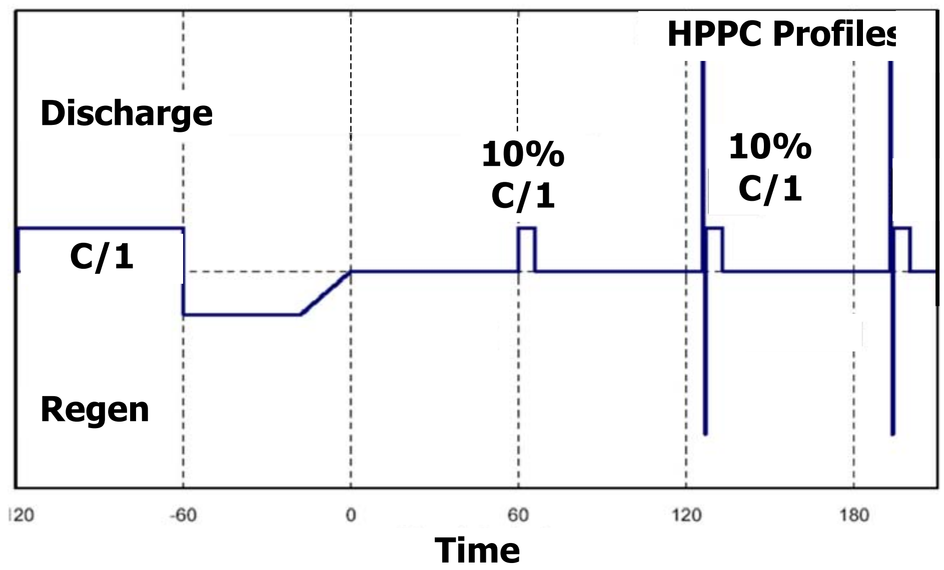
# Hybrid Pulse Power Test




**Hybrid Pulse Power Characterization (HPPC)**

PNGV Battery Test Manual, Feb., 2001

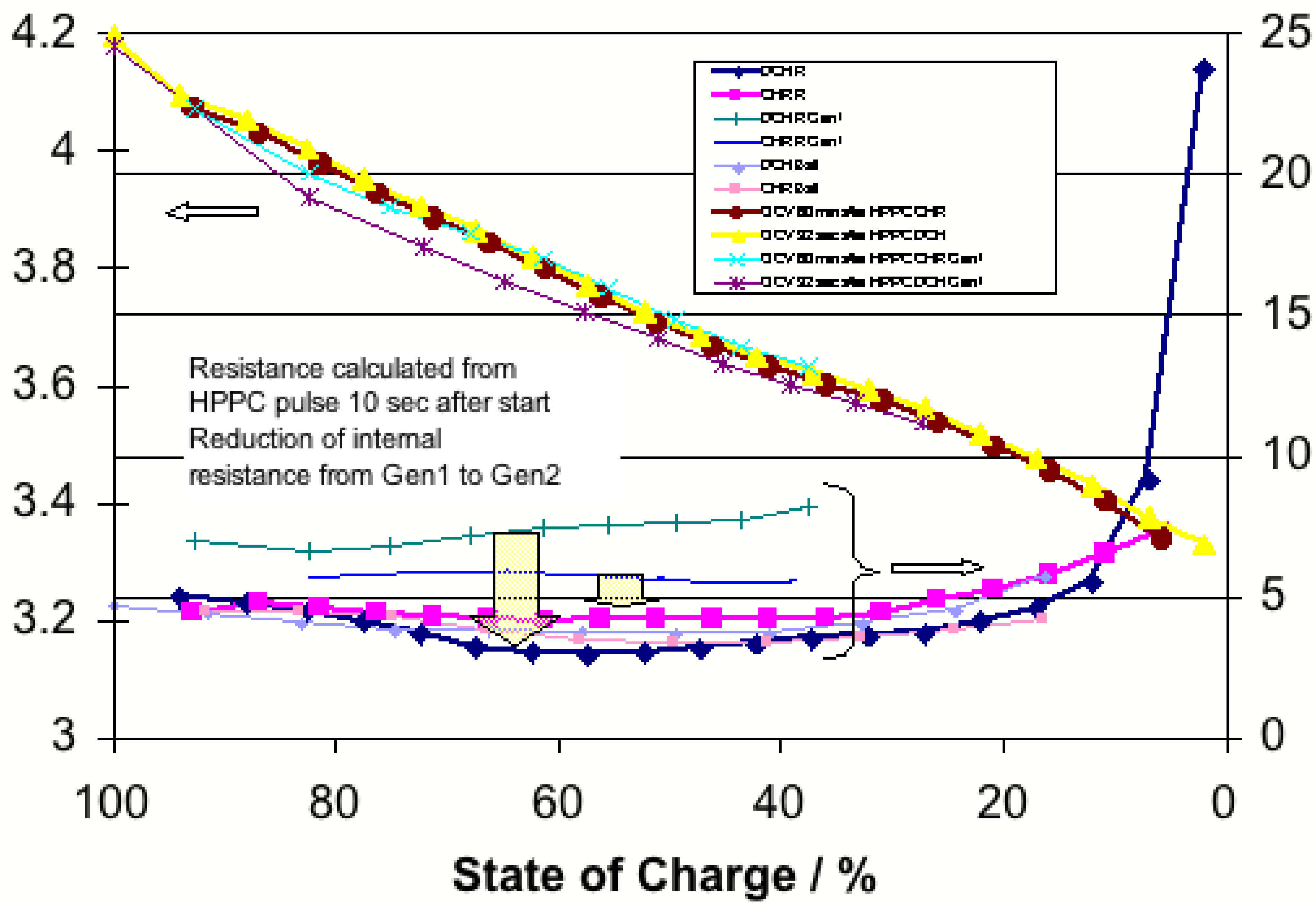
FreedomCAR Battery Test Manual For Power-Assist HEV, Oct., 2003



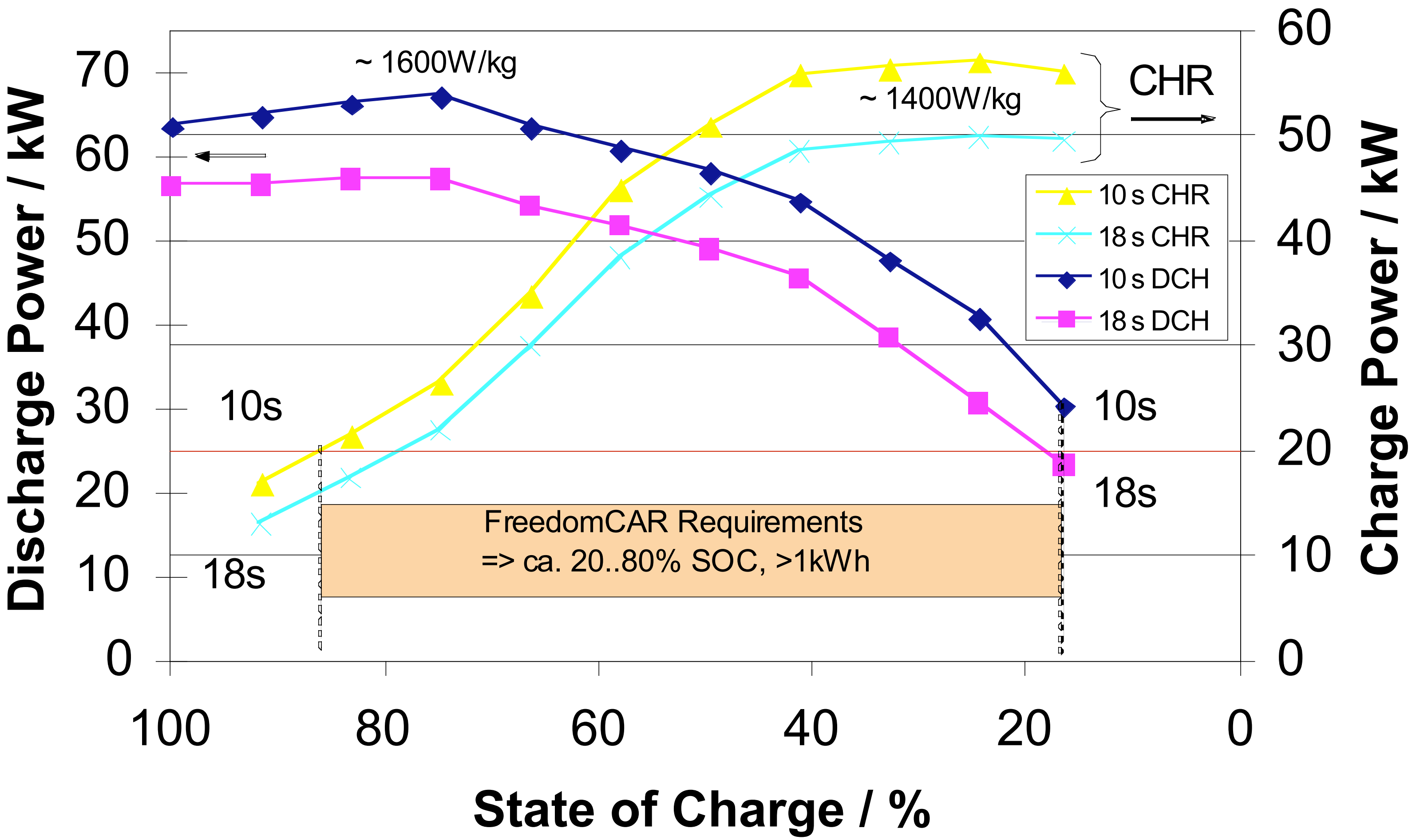
LTC Lithium Technology Corporation

GAIA Advanced Lithium Battery Systems

# Cells: Resistance and OCV



# Battery 288V: HPPC Profile




measurement by ZSW

Proprietary Information, November,2005

LTC Lithium Technology Corporation

GAIA Advanced Lithium Battery Systems

# Gap Analysis to USABC requirements

| | | PNGV | FreedomCar | | |
|---|---|---|---|---|---|
| **Characteristic** | **Unit** | **PA** | **PA Min** | **42V SS** | **achieved** |
| Pulse Discharge | kW | 18sec@25 | 10sec@25 | 2sec@6 | 70 |
| Pulse Charge (regen) | kW | 2sec@30 | 10sec@20 | N/A | 55 |
| Available Energy | kWh | 0.3 (@C/1) | 0.3 (@C/1) | 0.25 (@3kW) | 1 |
| Efficiency round-trip | % | 90 (25Wh) | 90 (25Wh) | 90 | 95 |
| Cold Cranking @ –30°C (3x 2sec, 10 sec. rests) | kW | 5 | 5 | 8 (21V Cold Start Profile) | 10 |
| Cycle Life | Cycles | 300k total 7.5MWh | 300k total 7.5MWh | 150k ZPA 450k Starts | >300k |
| Calendar Life | Years | 15 | | | 6-8 |
| Weight / Volume | kg / L | 40 / 32 | 40 / 32 | 10 / 9 | 42/40 |
| Max. Voltage | V | 440 | 400 | 48 (OCV) | 336 |
| Min. Voltage | V | $0.55 \cdot V_{max}$ | $0.55 \cdot V_{max}$ | 27 | 185 |
| Max. Self Discharge | Wh/Day | 50 | | 20 | 5%/m=4 |
| Operation Temperature | °C | -30 to +52 (-30 to 40°C) | | | -30..40 |
| Storage Temperature | °C | -46 to +66 (-40 to 60°C) | | | |
| Cost | $ | 300/kWh | 500/unit | 150/unit | more |

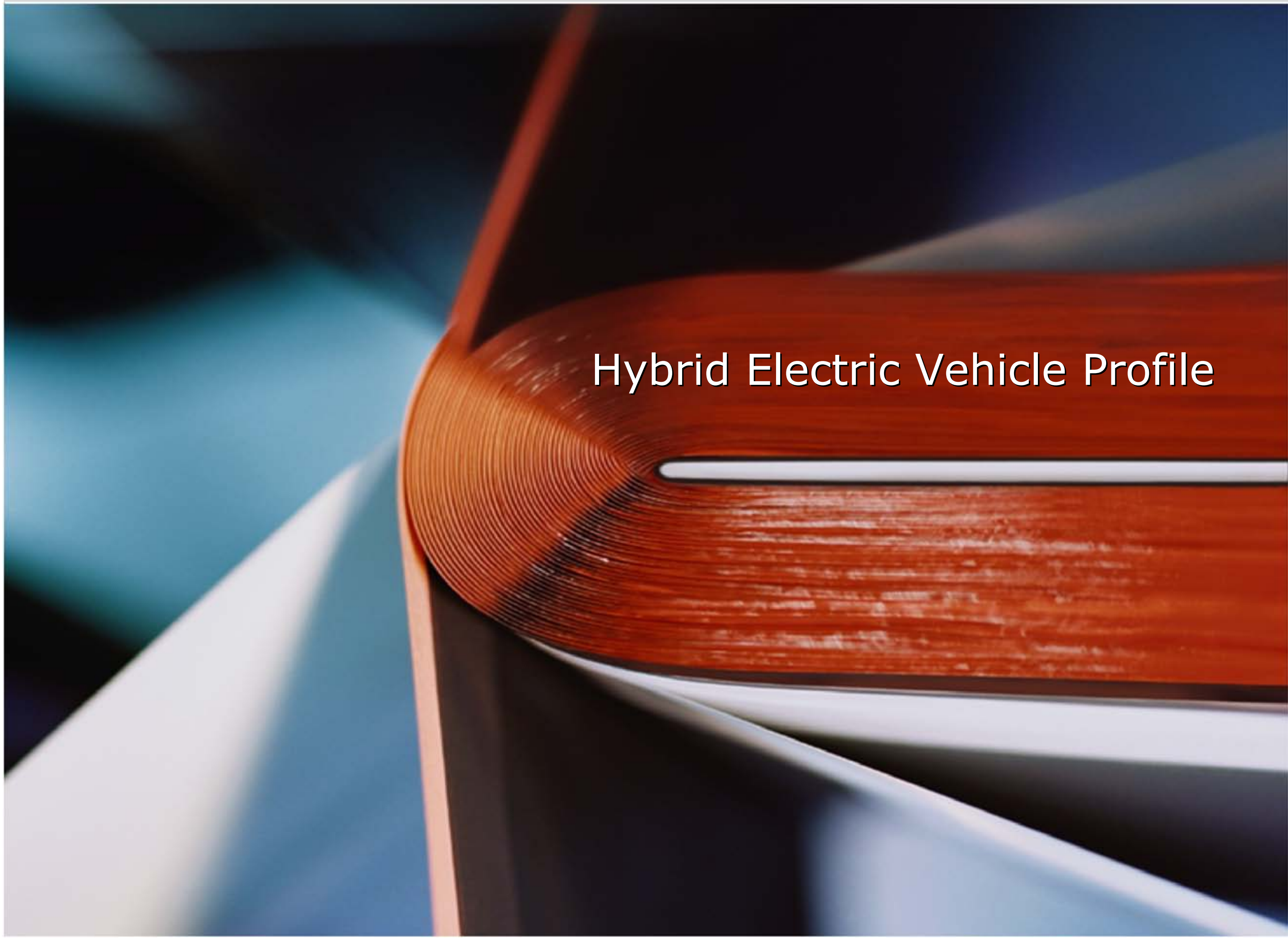
288 V / 2.1 kWh HEV Battery

Proprietary Information, November,2005

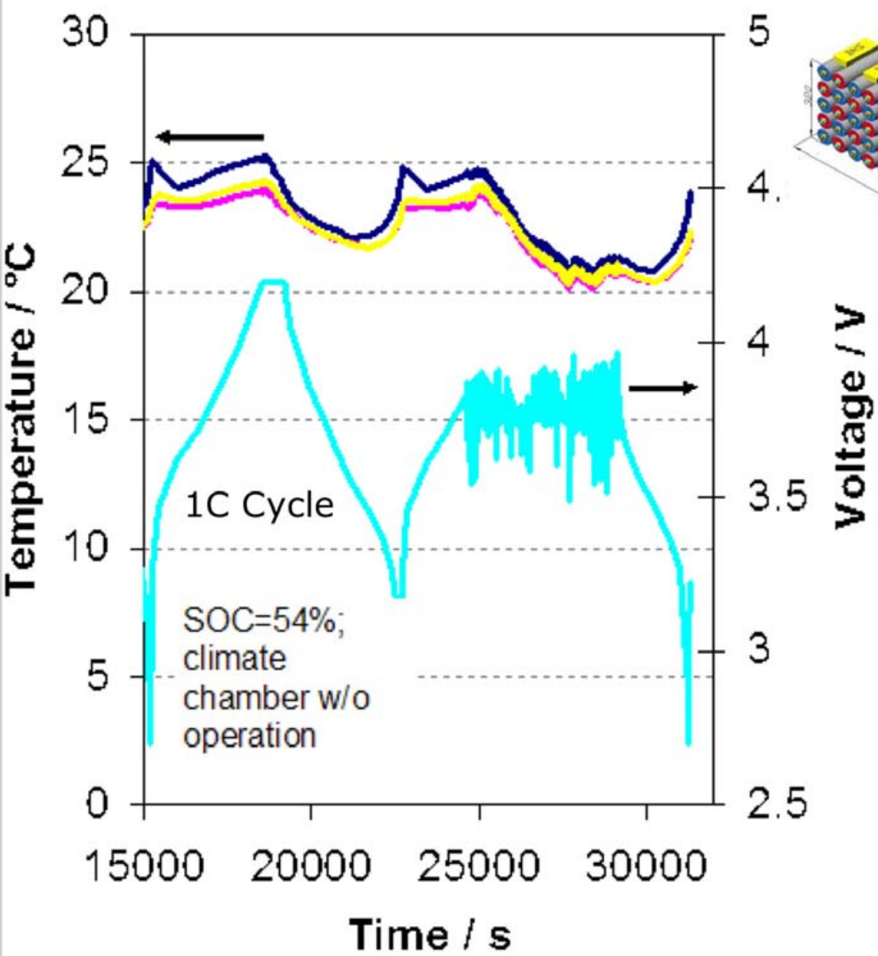
LTC Lithium
Technology Corporation

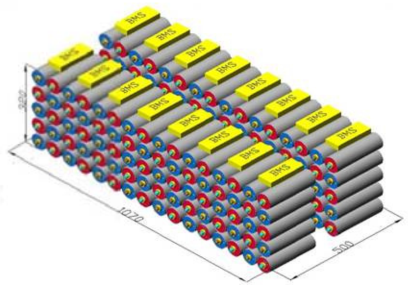
GAIA
Advanced Lithium Battery Systems

# Hybrid Electric Vehicle Profile

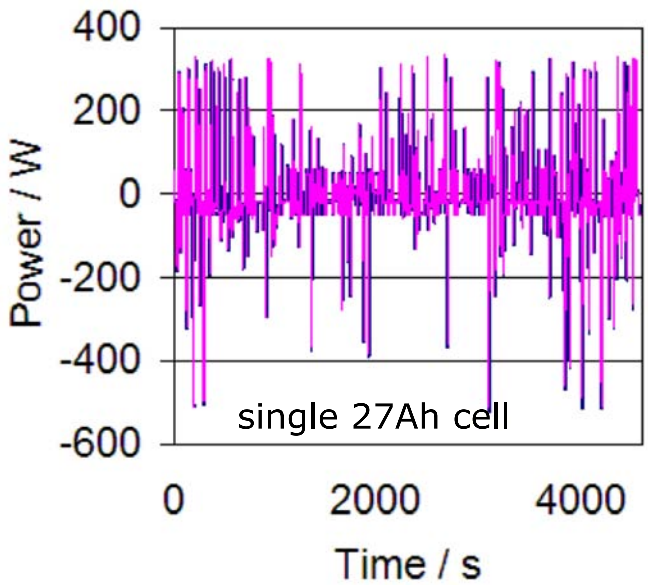


# Specification for HEV-Bus: 100kW with 45Ah Cells



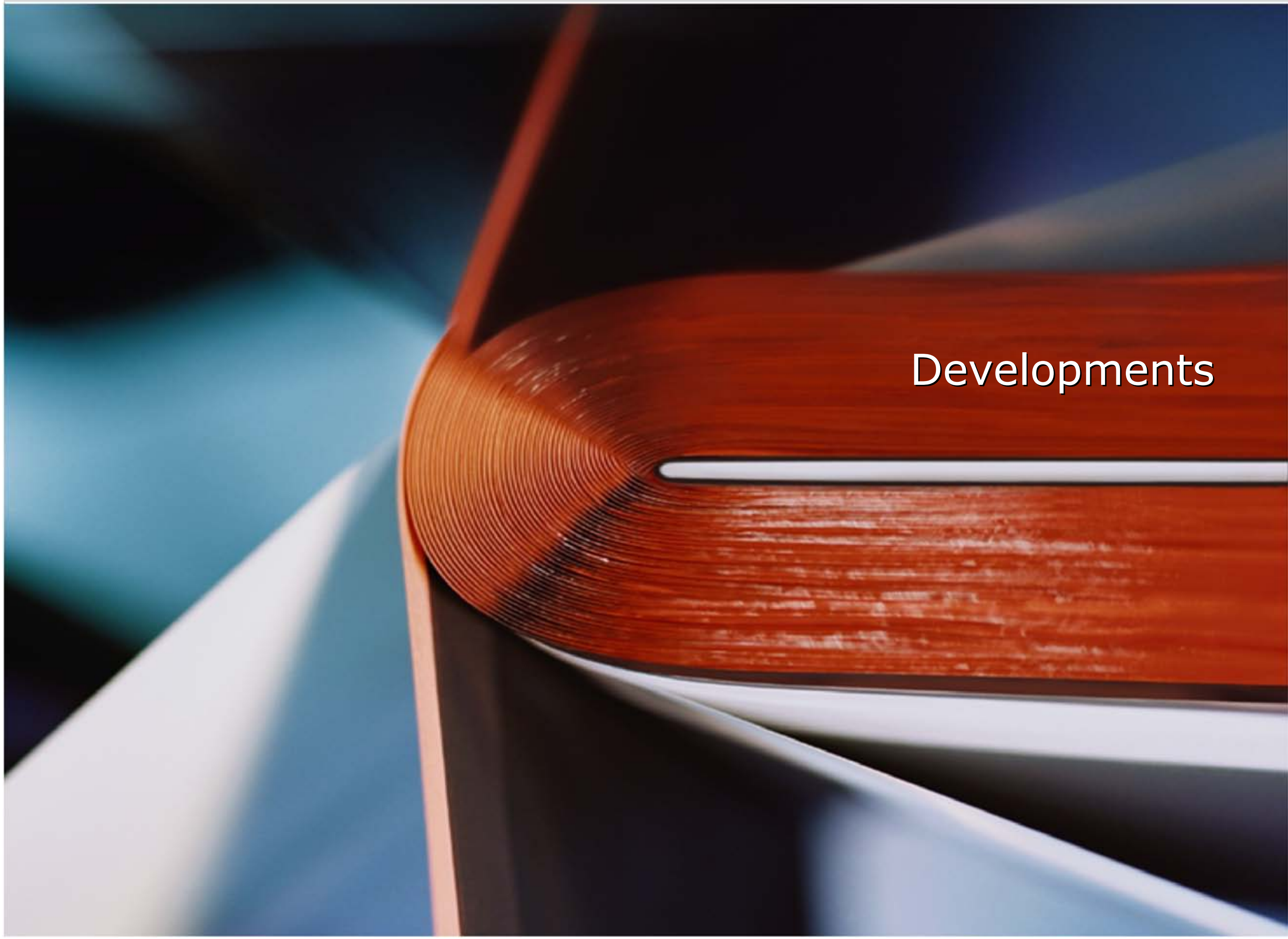



| | | |
|---|---|---|
| Cells | 160 | |
| Height | 320 | mm |
| Width | 500 | mm |
| Length | 1070 | mm |
| Volume | 171 | l |
| Weight Cells | 232 | kg |
| Packaging | 25 | % |
| Weight | 290 | kg |



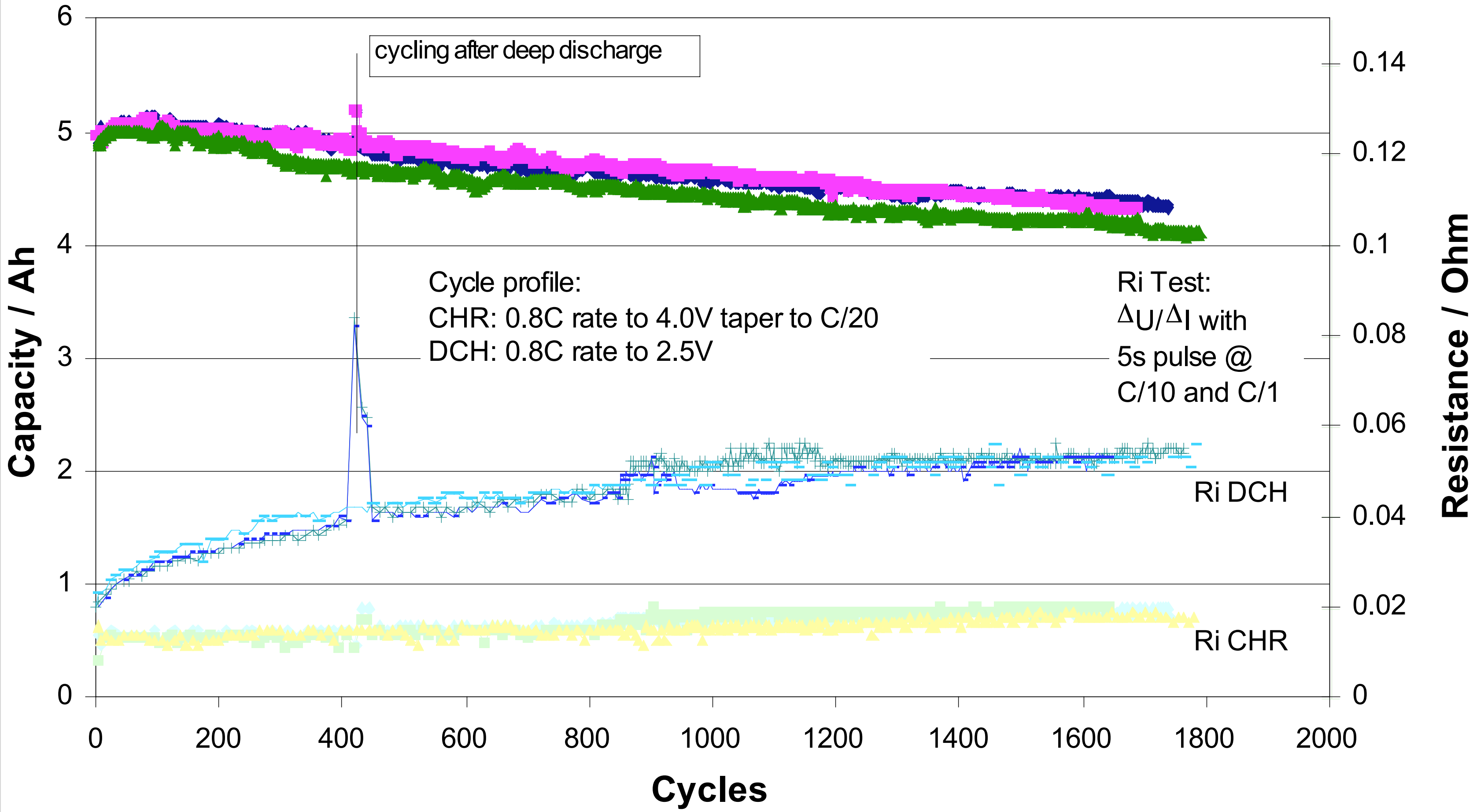
LTC Lithium
Technology Corporation

GAIA
Advanced Lithium Battery Systems



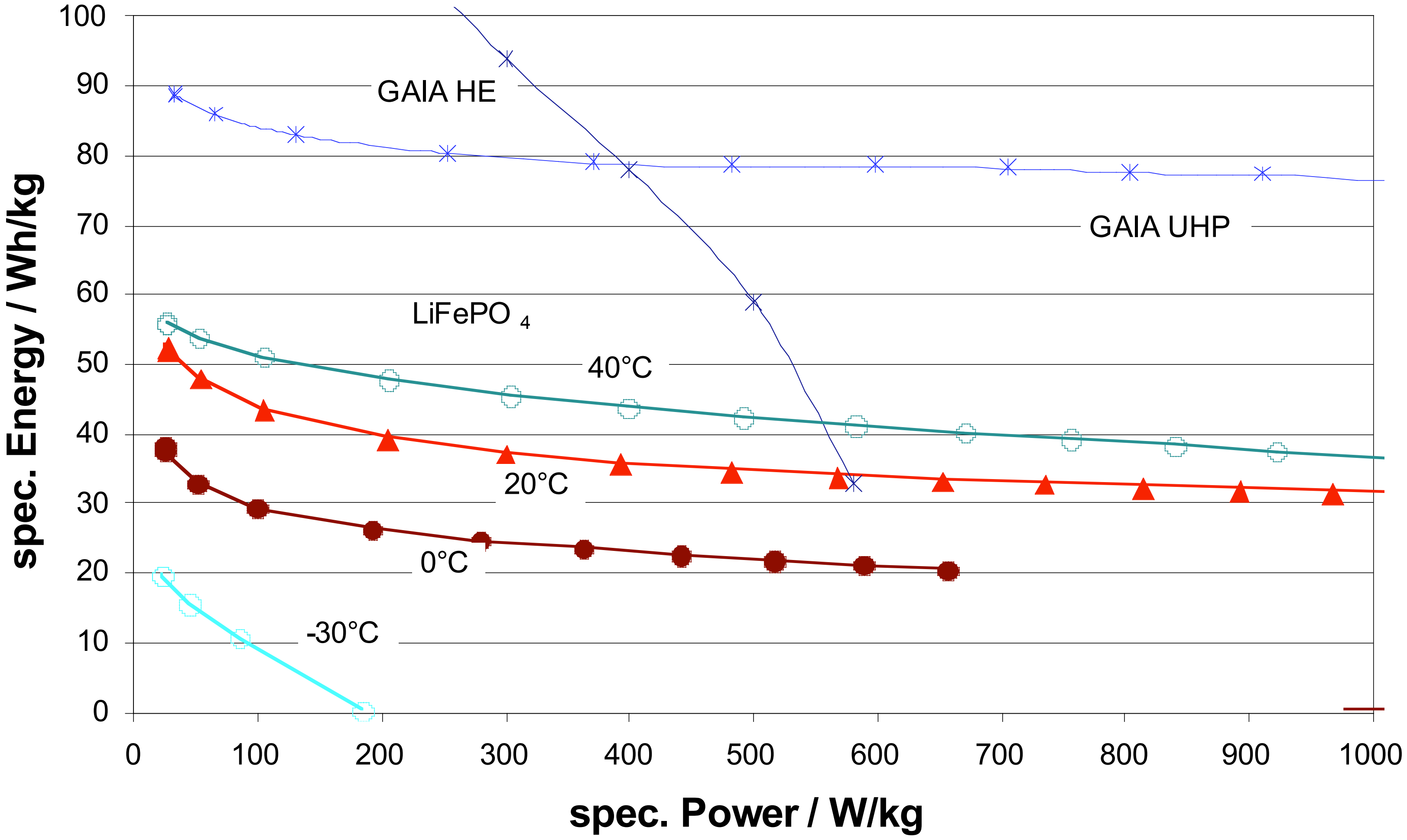
# Developments

# Cycling Data of $LiFePO_4$ System



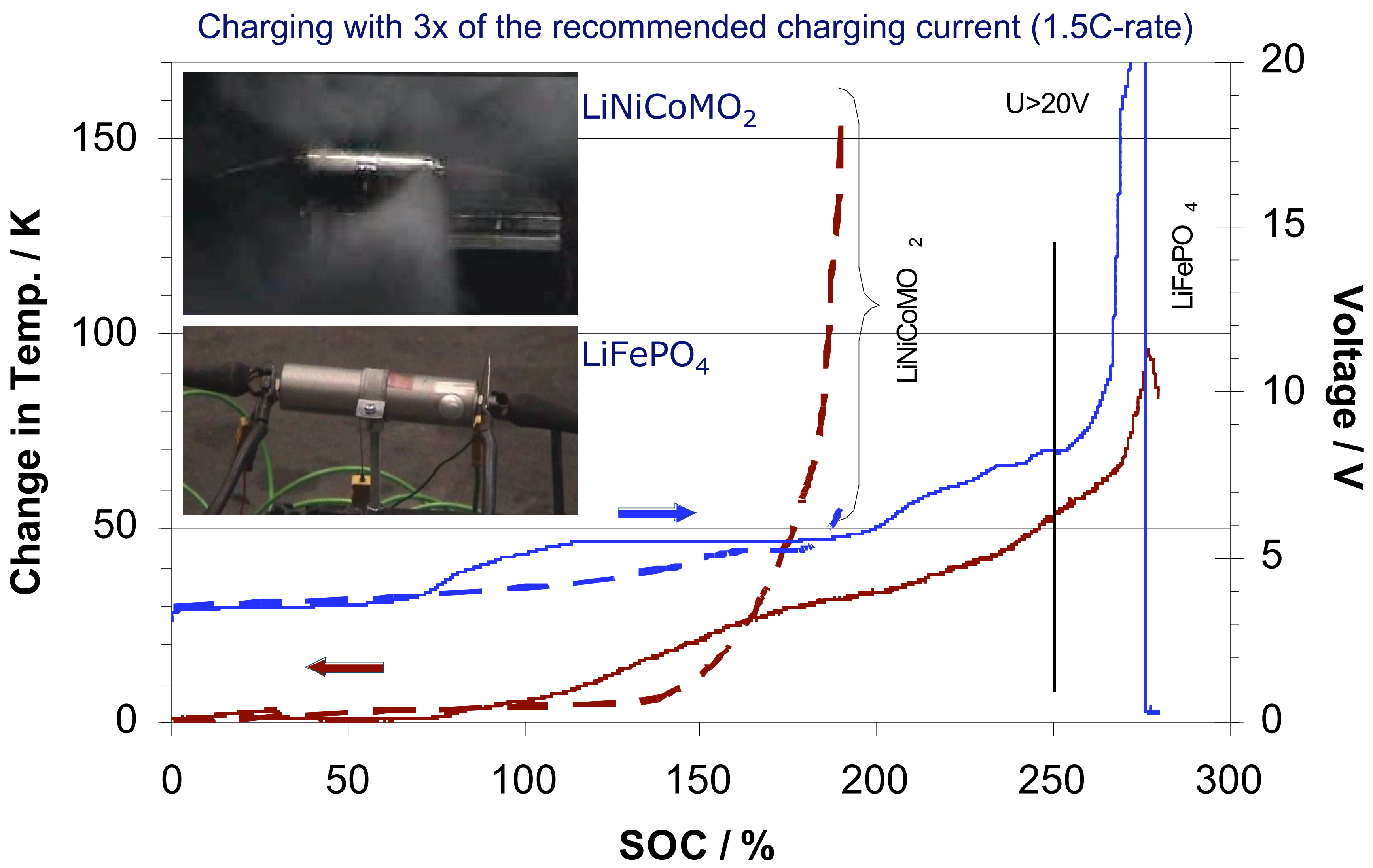

Proprietary Information, November,2005

# Ragone Plot DD-size Cell




Proprietary Information, November,2005

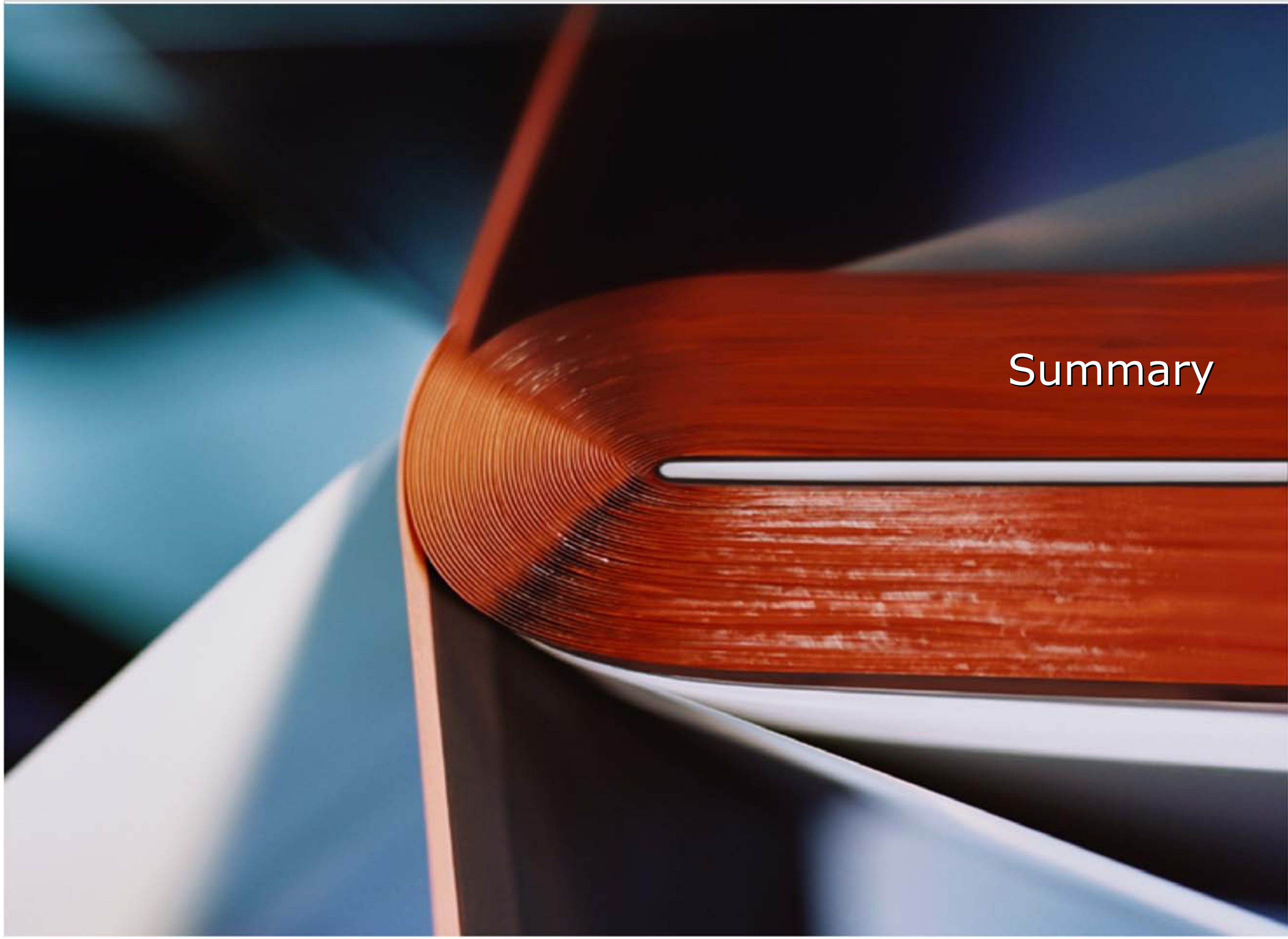
## Overcharging




Proprietary Information, November,2005

LTC Lithium Technology Corporation

GAIA Advanced Lithium Battery Systems



# Summary

- Large format, high power engineered Lithium Ion batteries are LTC's core expertise
  - Specific pulse power up to 2400 W/kg
  - Specific energy up to 150 Wh/kg
  - Cell energy content up to 216 Wh (60 Ah)
- LTC delivers customers with engineered battery packs from pilot facilities in Germany and the US
  - Military, transportation and stationary markets
  - Batteries up to 600 V
- Batteries with LTC's DD High Power cell meet the performance targets for Hybrid Electrical Vehicles
  - Power
  - Cycle life
  - Low temperature performance

Proprietary Information, November,2005