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*An OM Group Company*

# 6T Format Lithium Ion Batteries in 12V and 24V Configurations

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# Outline



- Project Overview
- Mechanical Design
- Electrical Design
- Performance Data
- Conclusions


# 6T Battery Background



- 6T is a NATO Standardized Form Factor
- Standardized From Factors Used in 95% of military vehicles
- Baseline is Lead Acid battery

* Baseline from TARDEC talk: June 19, 2012 by Yi Ding, PhD. Approved for public release.

# Project Overview

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- EaglePicher awarded contract by CALSTART to develop and deliver 12V and 24V Lithium-ion batteries in the 6T form factor
- 3 Lithium-ion replace 4 Lead-acid in Class 8 delivery vehicles
- 6 month project
  - Commercial parts
  - Limited lab testing
  - Emphasized field data
- Deliverables
  - (3) 12V batteries installed in a vehicle in California
  - (3) 12V batteries installed in a vehicle in Colorado
  - (6) 24V batteries delivered to TARDEC for characterization and Life Testing

# Application of 6T Batteries



- 6T batteries replaced common lead-acid batteries
- Kenworth T800B Class 8 Cab Truck Tractor used
- Similar truck show below

Photo from Kenworth T800 brochure, Kenworth Truck Co. U.S.A.

# California Installation

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- California Install (warm climate)
  - Vehicle ran delivery route in the southwest United States (Phoenix, Tucson, Las Vegas and the greater Los Angeles area)
  - Warm temperatures and anti-idling laws provided a challenging environment
  - Completed  4 months of field service
  - Batteries returned to EaglePicher for evaluation

# Colorado Installation

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- Colorado Install (cold climate)
  - Vehicle ran delivery route in the Colorado – New Mexico area
  - 4 month mission
  - Vehicle problem ended mission prematurely
  - Batteries were returned to EaglePicher

 

# Both Installations

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- Both installations included a data logger in the vehicle
  - Data logger: DRU900 from ISAAC Instruments connected to the truck J1939 outlet (CAN Bus), and IDN cable connected to battery BMS
  - Data sampling rate: 10 Hz for BMS parameters at startup, 1 Hz for all parameters
  - GPS receiver: Garmin G18 1 Hz

# Mechanical Design

- Cell selection - Safety
  - Lithium Iron Phosphate
  - 26650 configuration (cylindrical hard case)
  - 12V: 49P4S
  - 24V: 24P8S
- Battery Design
  - Terminals 3/8 – 16 threaded stud (adaptable to multiple platforms)
  - Aluminum container
  - Vent
  - J2 Communications connector
  - Handling straps
- Battery Physical Configuration
  - Nominal weight: 56 lbs/25.5 kg
  - Nominal Capacity: 120 AH/60 AH
  - Nominal Voltage: 13.2 V/26.4 V
  - Height: 10.00 inches
  - Width: 10.00 inches
  - Length: 10.51 inches

# EP's 6T Construction

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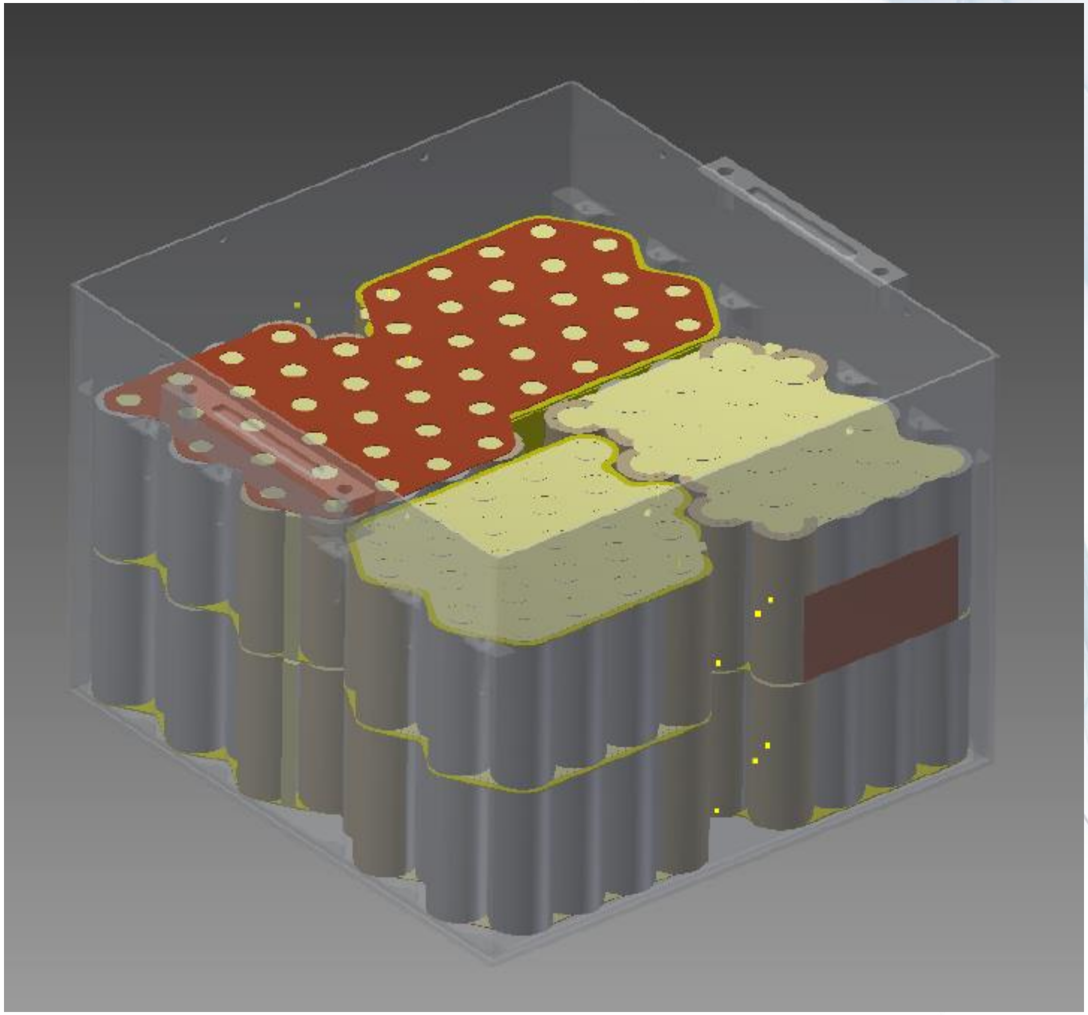
- Durable metal case
- Cylindrical cells
- Efficient packing
- Electronics
- Safety Systems



# Three 6Ts Installed

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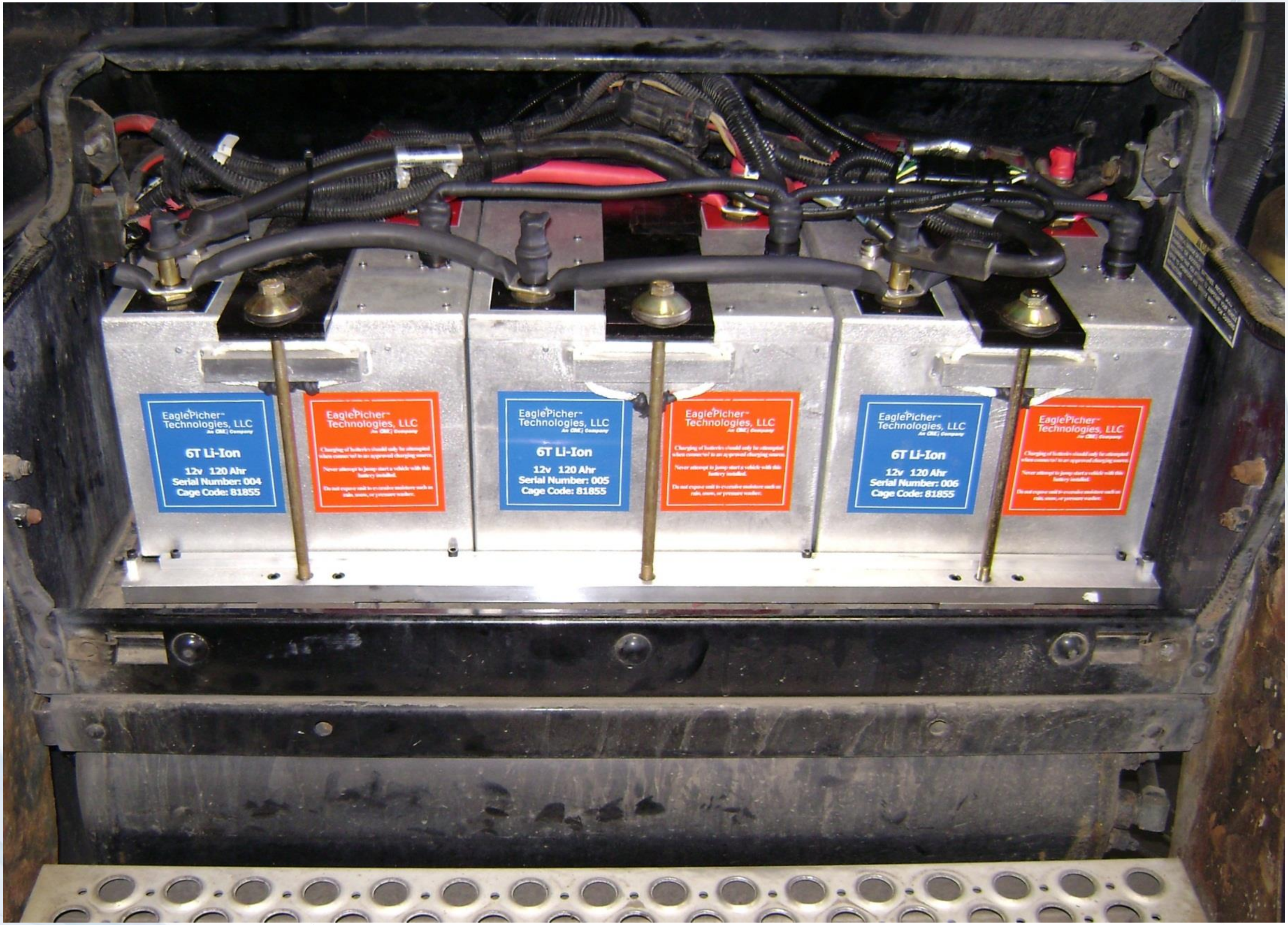

# Circuit Diagram of 6Ts in Truck

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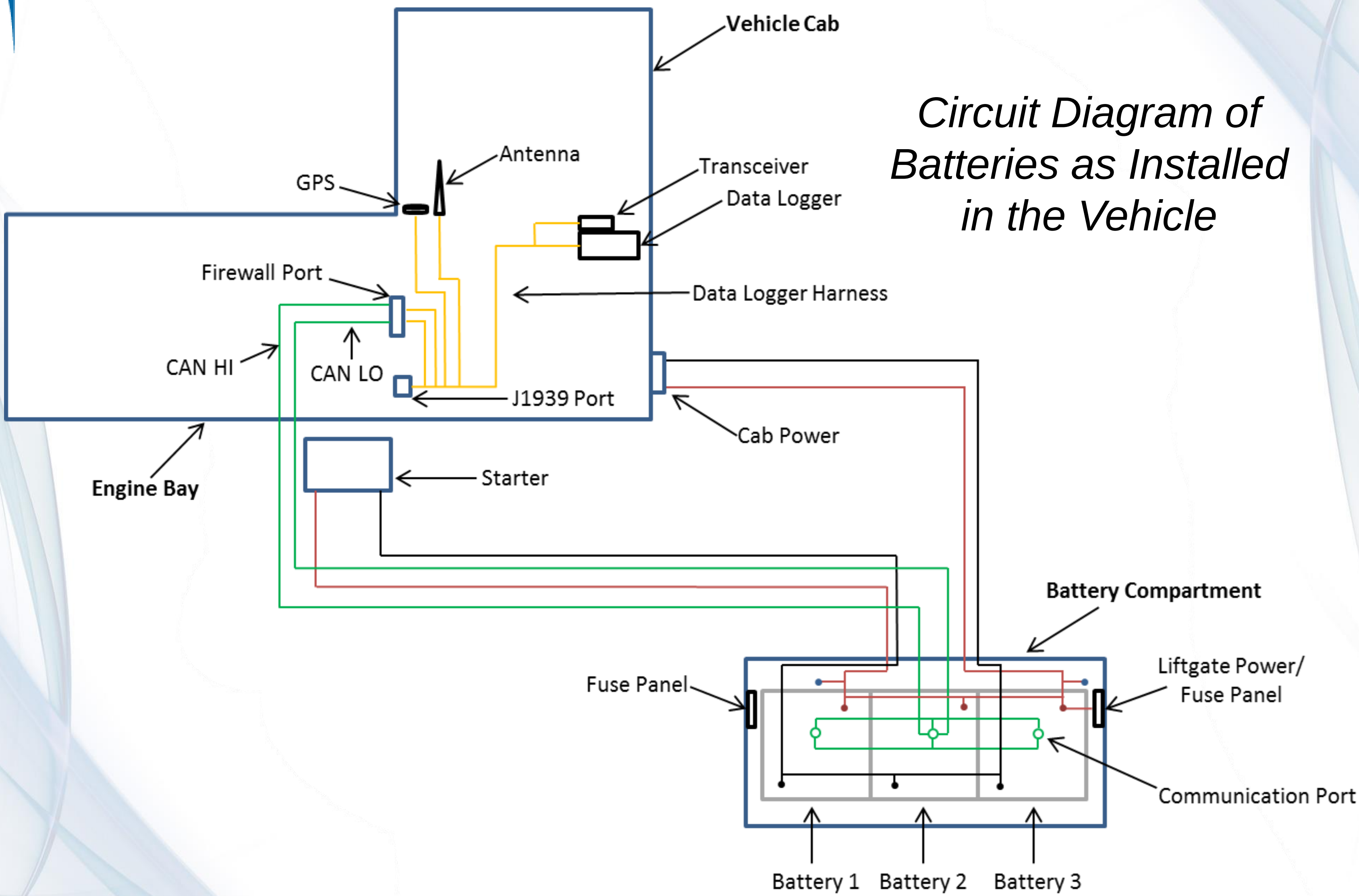


*Circuit Diagram of Batteries as Installed in the Vehicle*

# Electrical Design

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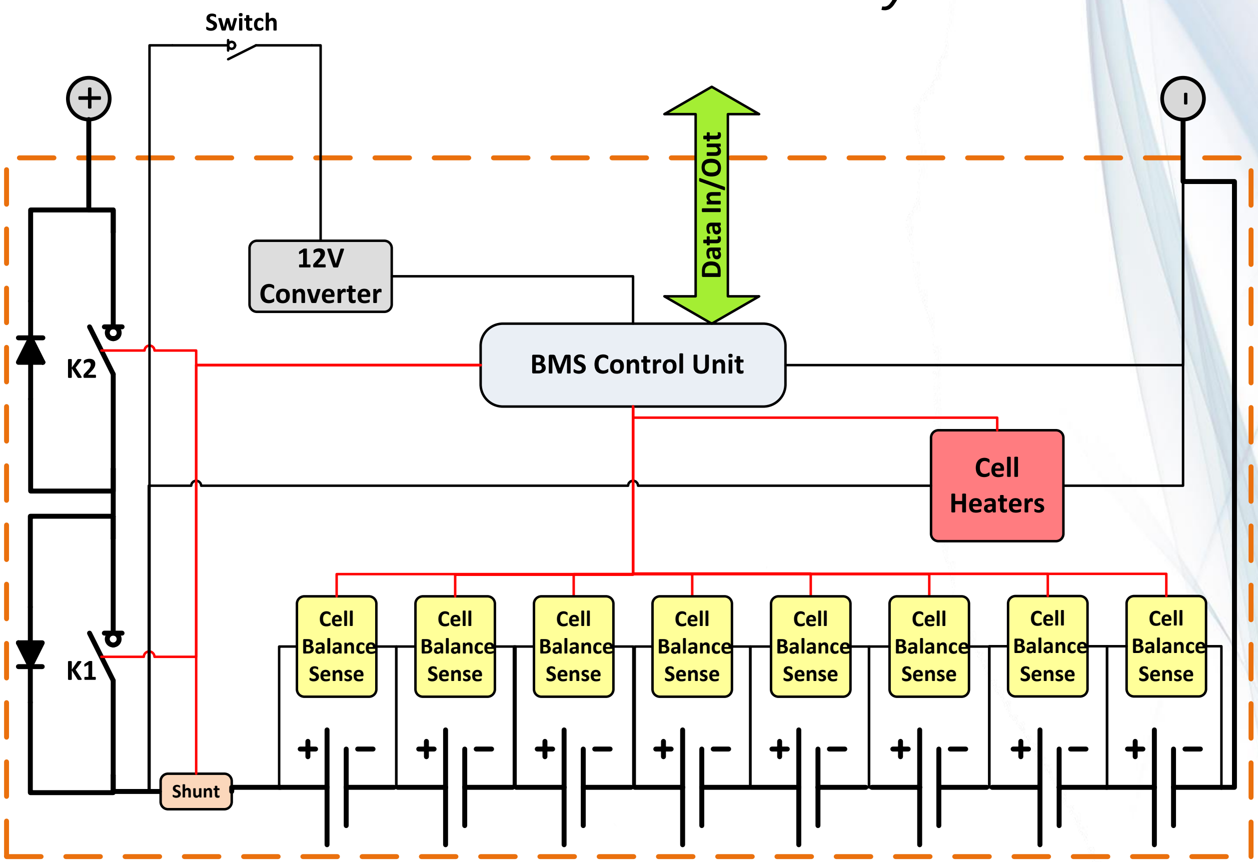
The BMS consist of the following primary components:

- BMS Control Unit
- K1 (normally open contactor)
- K2 (normally open contactor)
- Cell Balance and Sense Boards
- Cell Module Heaters
- Current Shunt
- 12V Converter (24V model only)

*Block Diagram of 24V Battery*



# Electrical Design: BMS

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## Battery Management System Control Unit

Primary Control and Oversight of Cells and Battery Operation

- The Control Unit is the focal point of the protection system
- Receive information from external sources, such as a key switch
- Send J1939 CAN data to an external data collection system
- Operates the individual Cell Balance Boards, Cell Heaters, Charge/Discharge Contactors
- It will also monitor for the following fault conditions
  - Over Temperature
  - Under Temperature
  - Over Current
  - Over Voltage
  - Under Voltage
  - Cell Communications
- Unit can be powered off with external switch for long term storage

## K1

Prevents Discharge

- Operation controlled by BMS Control Unit

# Electrical Design: BMS

**K2**

Prevents Charge

- Operation controlled by BMS Control Unit
- Closes when BMS Control Unit receives 12V or 24V signal from ignition switch

## Cell Balance and Sense Boards

Support Cell Balance and Sense Functions

- Shunt of variable amounts of current from the high voltage cells during charge
- Achieve uniformly charged cell modules
- Cell Voltage sense
- Cell Temperature sense
- Operation controlled by BMS Control Unit

## Cell Heaters

Maintain Proper Cell Temperatures

- Heat cells to acceptable temperature for charging
- Self heat cells to enhance cold weather starting capability
- Operation controlled by BMS Control Unit

# Performance Data (California Batteries)

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- 12V battery pack verification testing prior to shipment
  - Room temperature capacity cycle
  - 1000A discharge for 10 seconds
  - Verified Cold temperature heater operation
- Additional test to verify operation of 3 batteries in parallel
  - Charge (CC/CV)
  - 1000A discharge for 30 seconds
- Vehicle operation
  - Sep 2013 – Dec 2013
- 12V battery pack verification testing after field service
  - OCV after removal from the vehicle
  - Room temperature capacity cycle
  - 1000A discharge for 30 seconds, 3 batteries in parallel
- Visual inspection for damage

# Performance Data

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| Days in Operation | Miles | Starts | Idle Time | Min Air Temp | Max Air Temp |
|---|---|---|---|---|---|
| 52 | 9030.3 | 1536 | 18% | -16.34°C | 37.34°C |

***Vehicle In-Service Statistics***

| Battery | Min Cell Voltage | Max Cell Voltage | Min Cell Temp | Max Cell Temp |
|---|---|---|---|---|
| 001 | 3.32V | 3.65V | +5°C | +51°C |
| 002 | 3.30V | 3.67V | +7°C | +53°C |
| 003 | 3.32V | 3.67V | +7°C | +51°C |

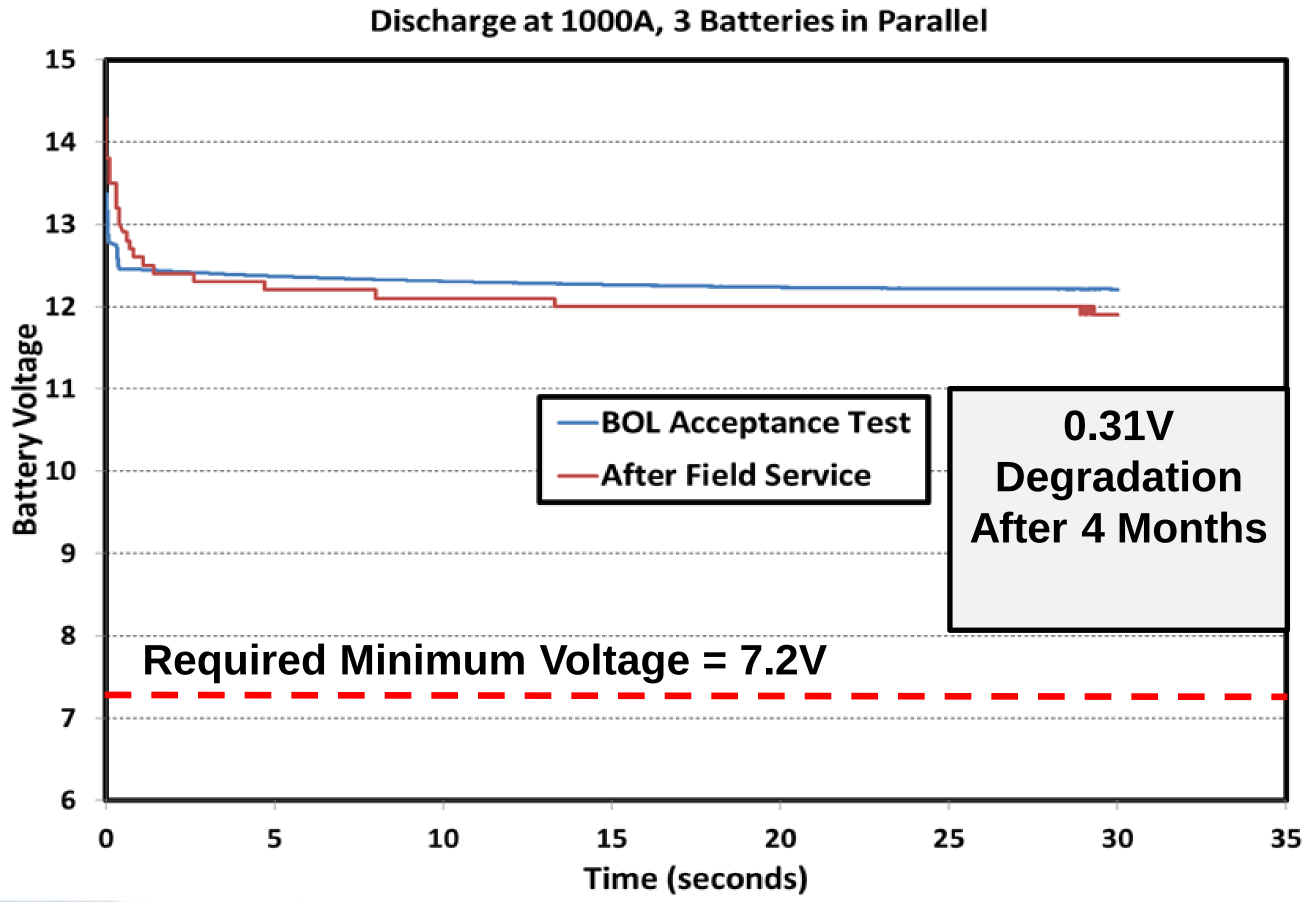
***Battery In-Service Statistics***

| Battery | Open Circuit Voltage | Min Cell Voltage | Max Cell Voltage |
|---|---|---|---|
| 001 | 13.24V | 3.31V | 3.31V |
| 002 | 13.22V | 3.30V | 3.31V |
| 003 | 13.23V | 3.30V | 3.31V |

***Battery Health after Removal from Vehicle***

# Life Predictions

- Capacity degradation and voltage degradation characterized at room temp
  - Capacity loss = 1.77AH per month
  - EOD Voltage loss = 0.077V per month (@ starter load = 1000A)



# Life Predictions: continued

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- Life Predictions, Cont.
  - It is known that the battery will need to be heated to TBD°C in order to support the starter load requirement
  - For this analysis we have assumed TBD = 20°C since our degradation rates have been calculated at this temperature
  - What we know
    - Power usage of heaters (AH/°C)
    - Capacity used to make a start attempt
    - BOL Capacity and Voltage
    - Capacity and Voltage degradation rates
    - Cell voltage vs SOC
- Calculations
  - Assume an ambient temperature < 20°C
  - Calculate heater load to reach ambient (AH)
  - Calculate resulting SOC of battery and corresponding cell voltage
  - Predict life based on capacity = SOC after start / capacity degradation rate
  - Adjust EOD voltage based on SOC after heating
  - Predict life based on voltage = adjusted EODV / voltage degradation rate

# Life Predictions: continued

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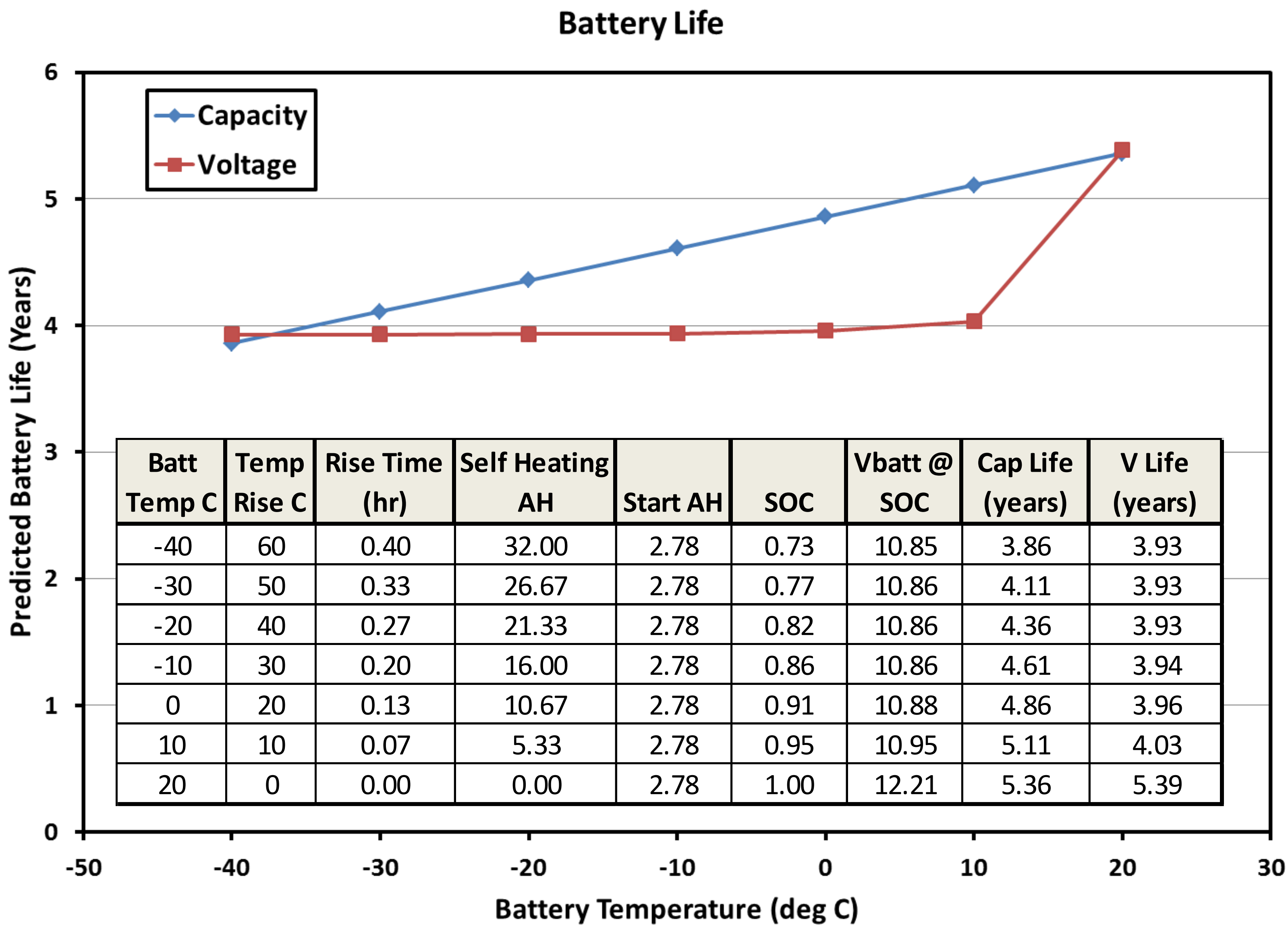


| Batt Temp C | Temp Rise C | Rise Time (hr) | Self Heating AH | Start AH | SOC | Vbatt @ SOC | Cap Life (years) | V Life (years) |
|---|---|---|---|---|---|---|---|---|
| -40 | 60 | 0.40 | 32.00 | 2.78 | 0.73 | 10.85 | 3.86 | 3.93 |
| -30 | 50 | 0.33 | 26.67 | 2.78 | 0.77 | 10.86 | 4.11 | 3.93 |
| -20 | 40 | 0.27 | 21.33 | 2.78 | 0.82 | 10.86 | 4.36 | 3.93 |
| -10 | 30 | 0.20 | 16.00 | 2.78 | 0.86 | 10.86 | 4.61 | 3.94 |
| 0 | 20 | 0.13 | 10.67 | 2.78 | 0.91 | 10.88 | 4.86 | 3.96 |
| 10 | 10 | 0.07 | 5.33 | 2.78 | 0.95 | 10.95 | 5.11 | 4.03 |
| 20 | 0 | 0.00 | 0.00 | 2.78 | 1.00 | 12.21 | 5.36 | 5.39 |

 

# 6T Battery Comparison

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- Baseline Lead Acid vs EPT's Li-Ion

| | Baseline 6T Lead Acid * | EPT's 6T Li-Ion |
|---|---|---|
| Voltage | 12V | 12 or 24 V |
| Capacity | 120 Ahr (C/20) | 120 Ahr (Nominal, 12V) |
| Energy Density | 36 Wh/kg | 57 Wh/kg |
| Weight | 40 kg | 25.5 kg |
| Class 8 Truck System | 4 Batteries | 3 batteries |

* Baseline from TARDEC talk: June 19, 2012 by Yi Ding, PhD. Approved for public release.

# Conclusions

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- Designs successfully integrated COTS parts into the 6T form factor
- Vehicle installation provided valuable exposure to actual field conditions
- Performance data after field service indicates BMS adequately managed cell health and safety
- Significant weight savings
  - EP 6T = 57Whr/kg, Typical Lead-acid = 40 Whr/kg (30% Savings)
  - 3 Lithium-ion replace 4 Lead acid (25% savings)
- Projected life of Lithium-ion solution is 4-5 years
- EaglePicher's 6T Lithium-ion battery provides a safe solution with significant technical advantages

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- CALSTART: Ted Bloch-Rubin, Jasna Tomic, Jean-Baptiste Gallo
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