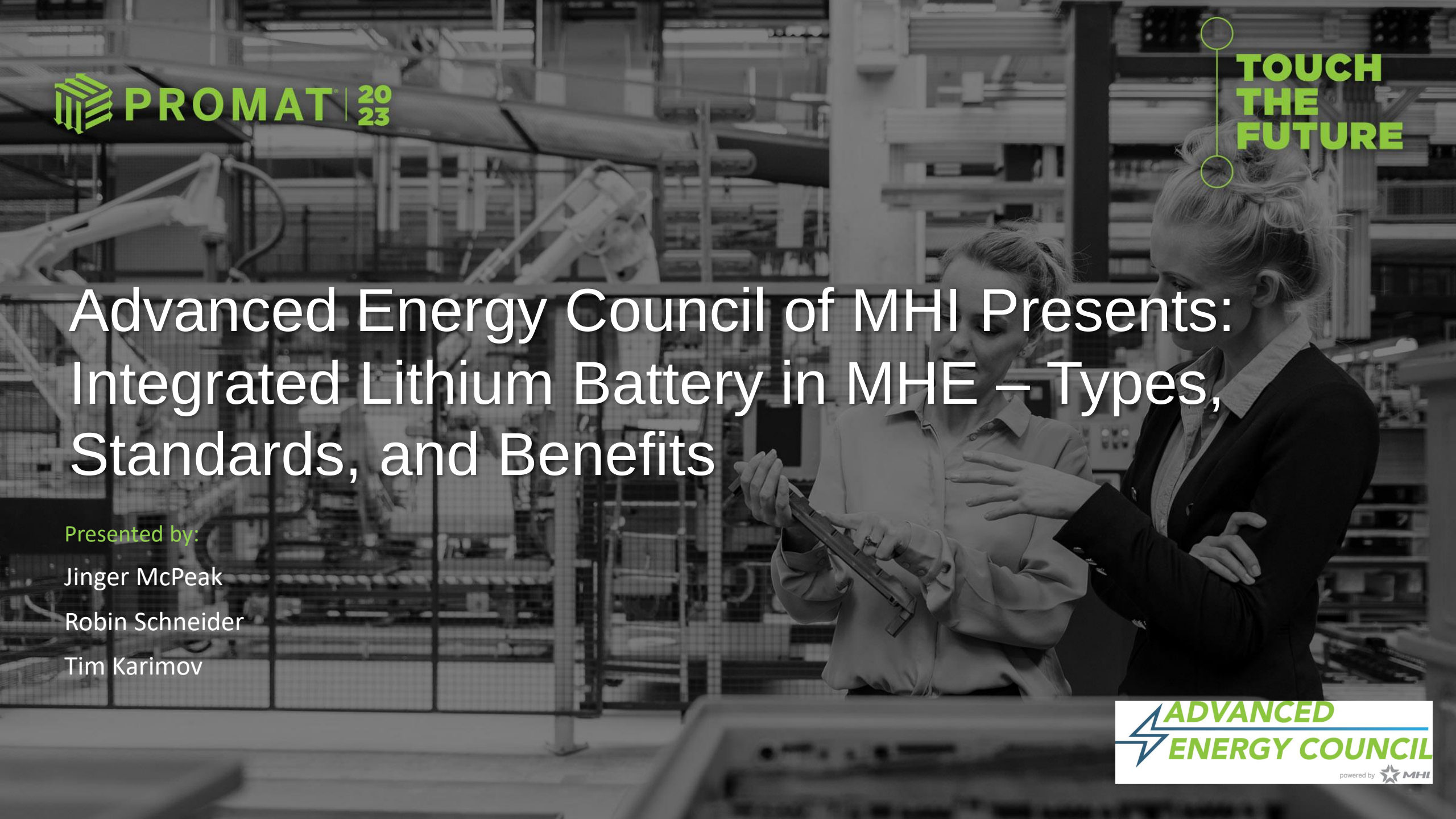


# Advanced Energy Council of MHI Presents: Integrated Lithium Battery in MHE – Types, Standards, and Benefits

Presented by:

Jinger McPeak

Robin Schneider

Tim Karimov

ADVANCED ENERGY COUNCIL
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**Jinger McPeak**
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**Tim Karimov**
*President*
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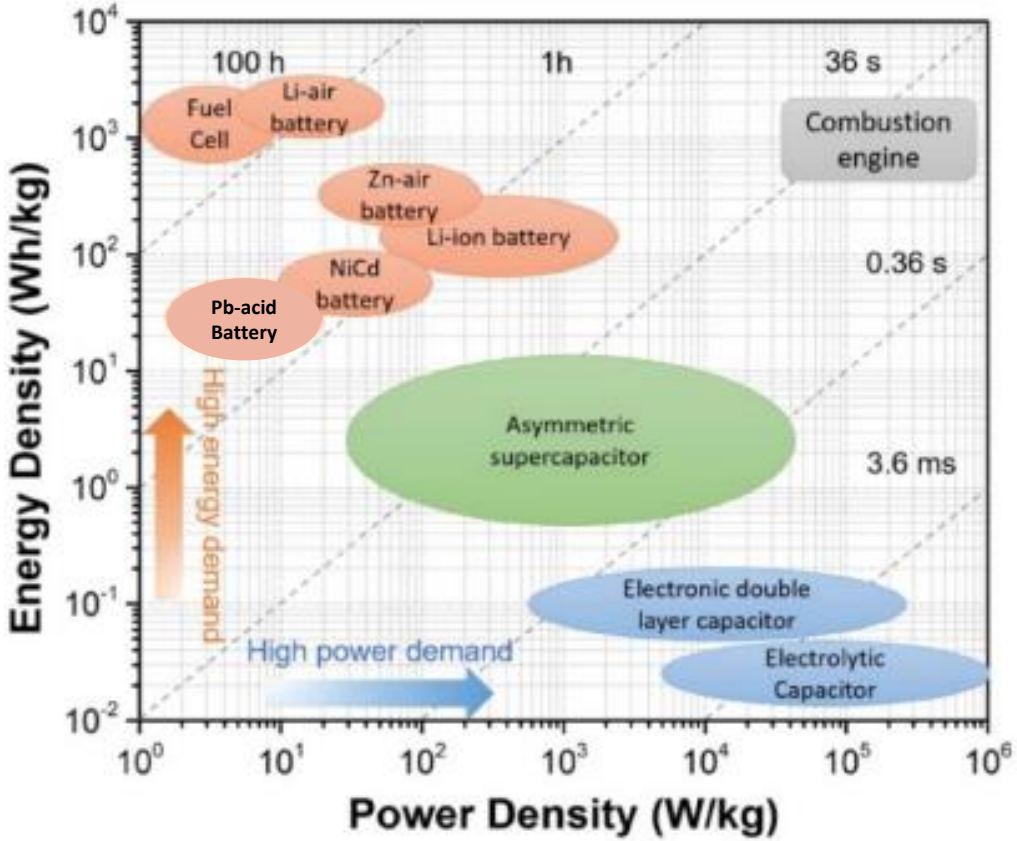
| Raymond Corporation | S1703 & S1903 |
| UgoWork | N6760 |
| Wiferion North America Inc. | N8318 |

# History

## Innovation evolves slowly

- Lead acid battery invented:1860
- Combustion engine invented:1872
- First motor car:1886
- Li-ion invented: 1985
- LFP invented: 1996
- Honda launches EV plus, Lead acid based: 1997
- First Li-ion based Laptop: ~1998
- I-phone launch: 2007
- Tesla launches Li-ion Roadster: 2008
- First Material Handling Batteries: 2010
- Noble Prize in Chemistry awarded for Li-ion invention: 2019

# Technology for Energy Conversion and Storage

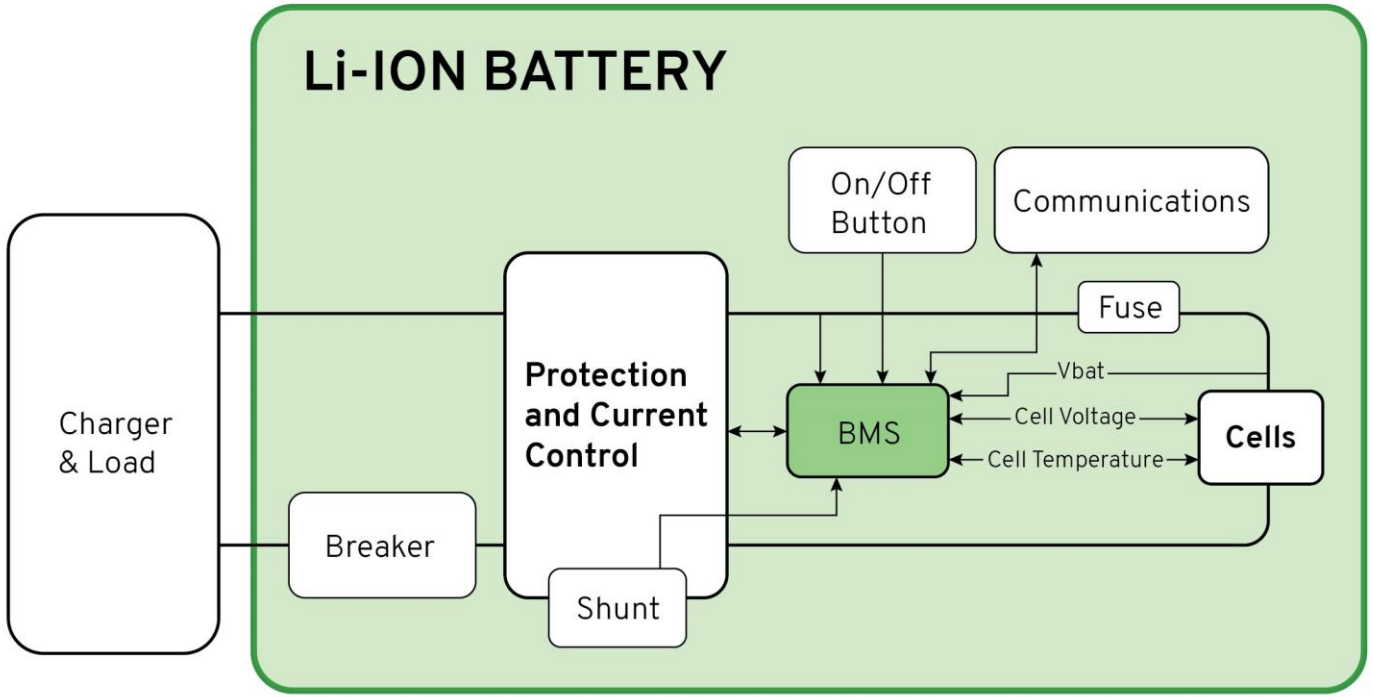


# Li-ion Advantages

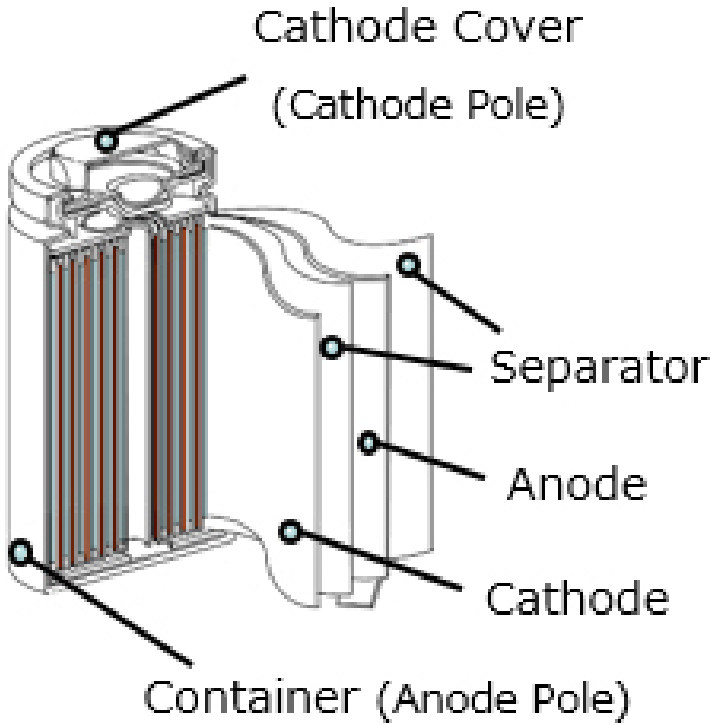
Varies widely by specific cell

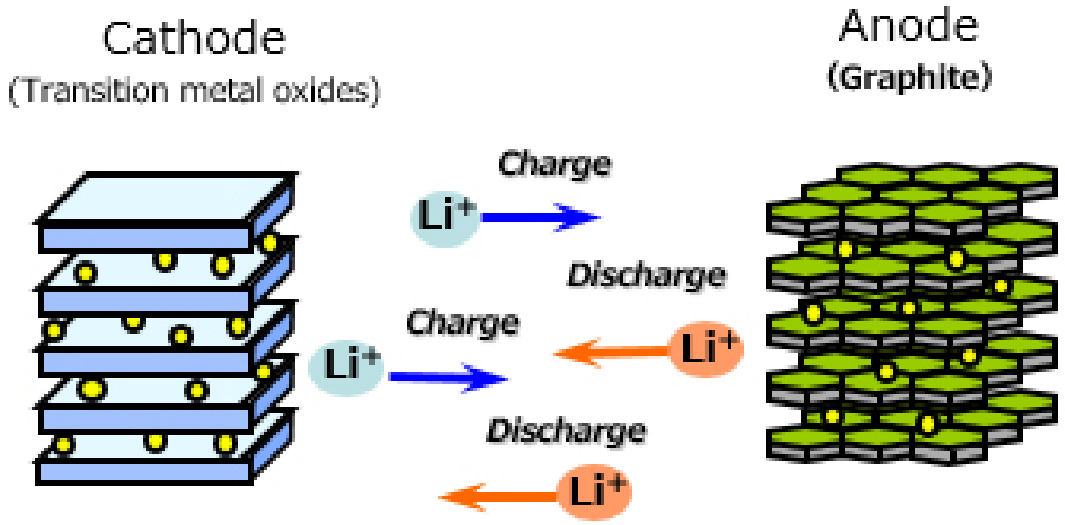
- High energy density (weight an volume)
- High voltage
- Good cycle life
- Good temp operating range
- Low self discharge
- Low maintenance (no memory effect)
- Flat discharge curve

# What is a Li-ion Battery Pack?



# Li-ion Cell Components

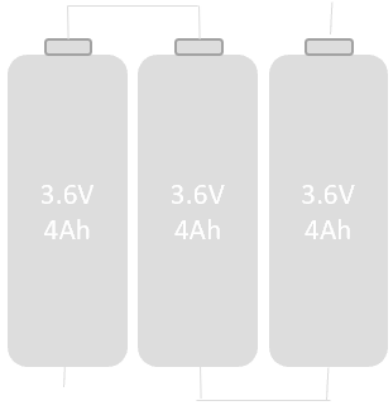


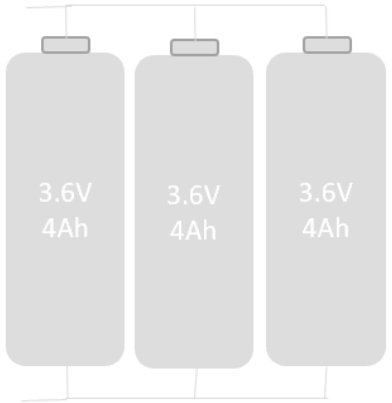
# Building Capacity and Voltage

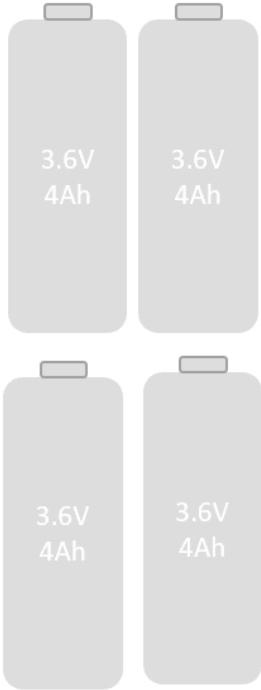
- Series to increase voltage, Parallel to increase capacity (same Wh)

- Series=positive to negative
- 3S1P=10.8V, 4Ah



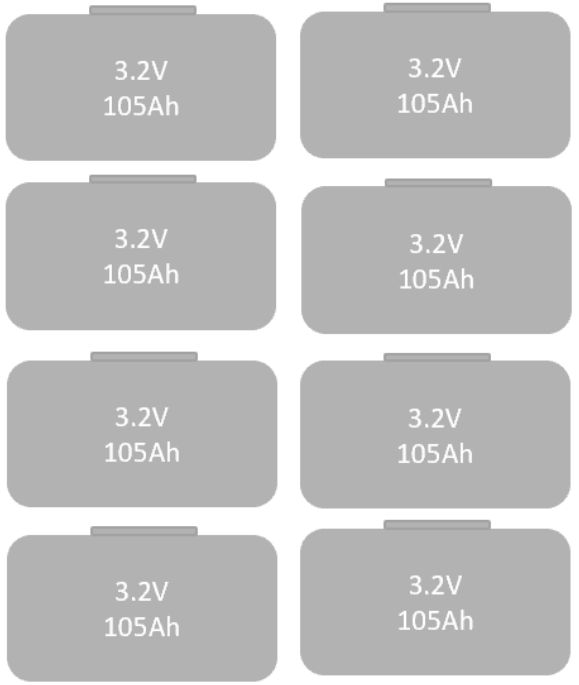

- Parallel=positive to positive and negative to negative
- 1S3P=3.6V, 12Ah



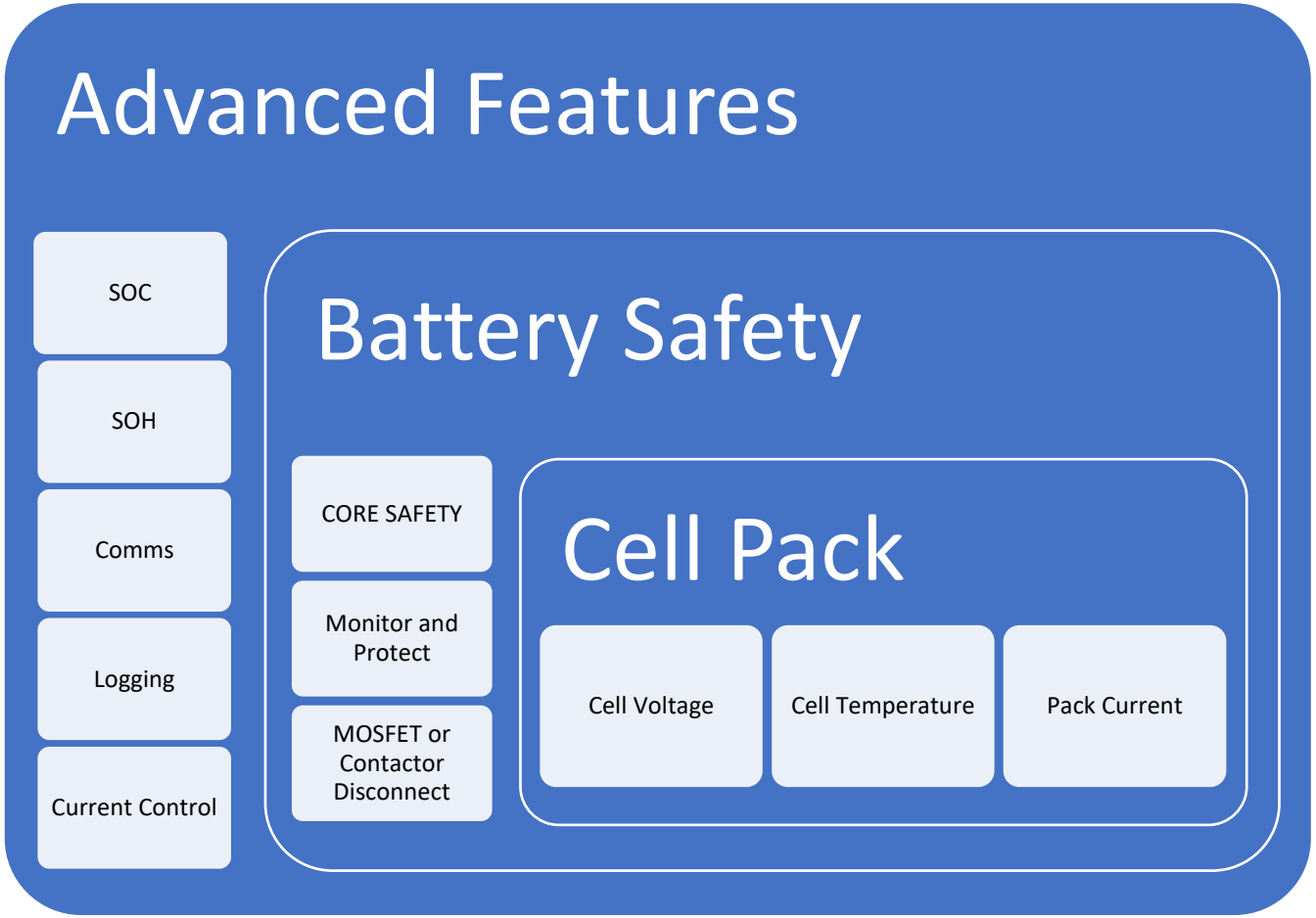

- 2S2P=7.2V, 8Ah

- 4S2P=12.8V, 210Ah



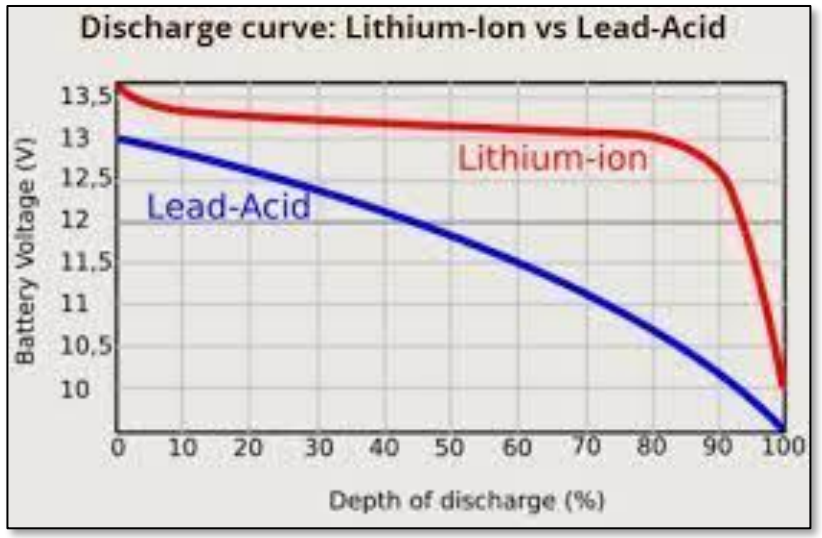
# Battery Management Systems (BMS)

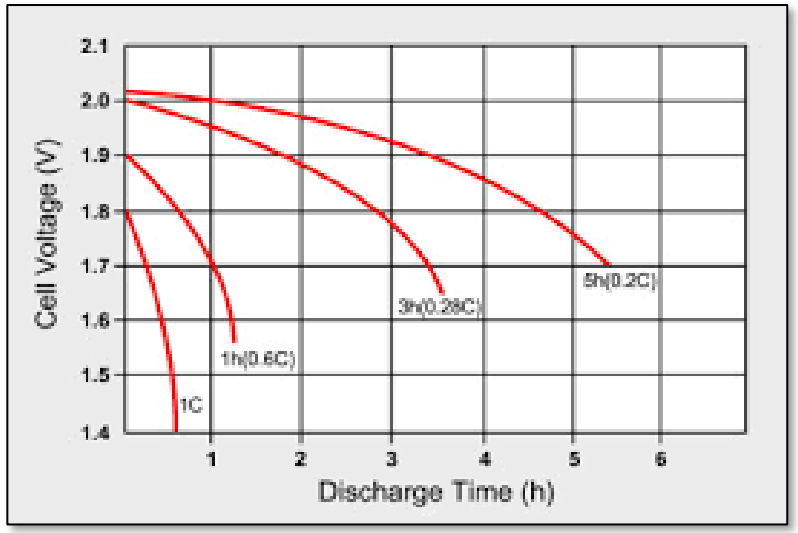
- Core Safety Functions
  - V, I, T Monitoring
  - Safety Disconnect
- Advanced Functions
  - State of Charge
  - State of Health
  - Heating and Cooling
  - Monitoring and Logging
  - Remote Communication
  - Advanced Current Control
  - Safety Integrity Level (SIL)
  - Inverter/System Control
  - Cell balancing

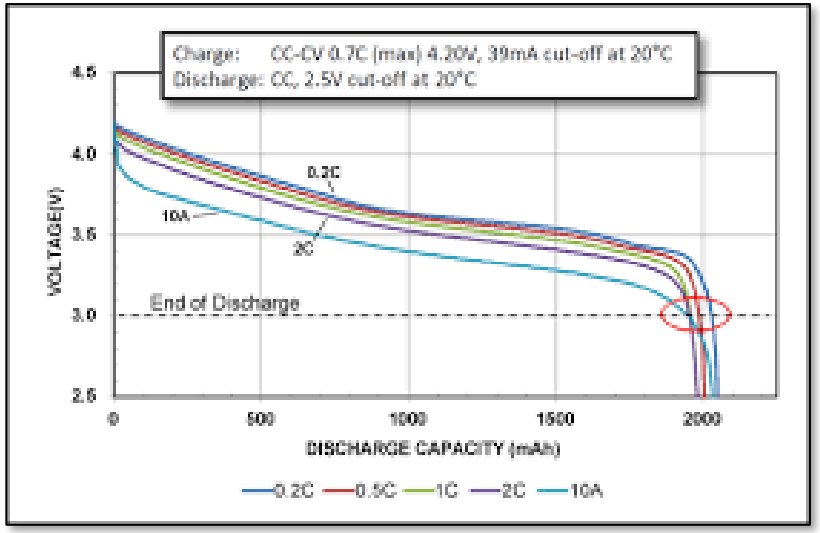


# Battery Discharge Curve

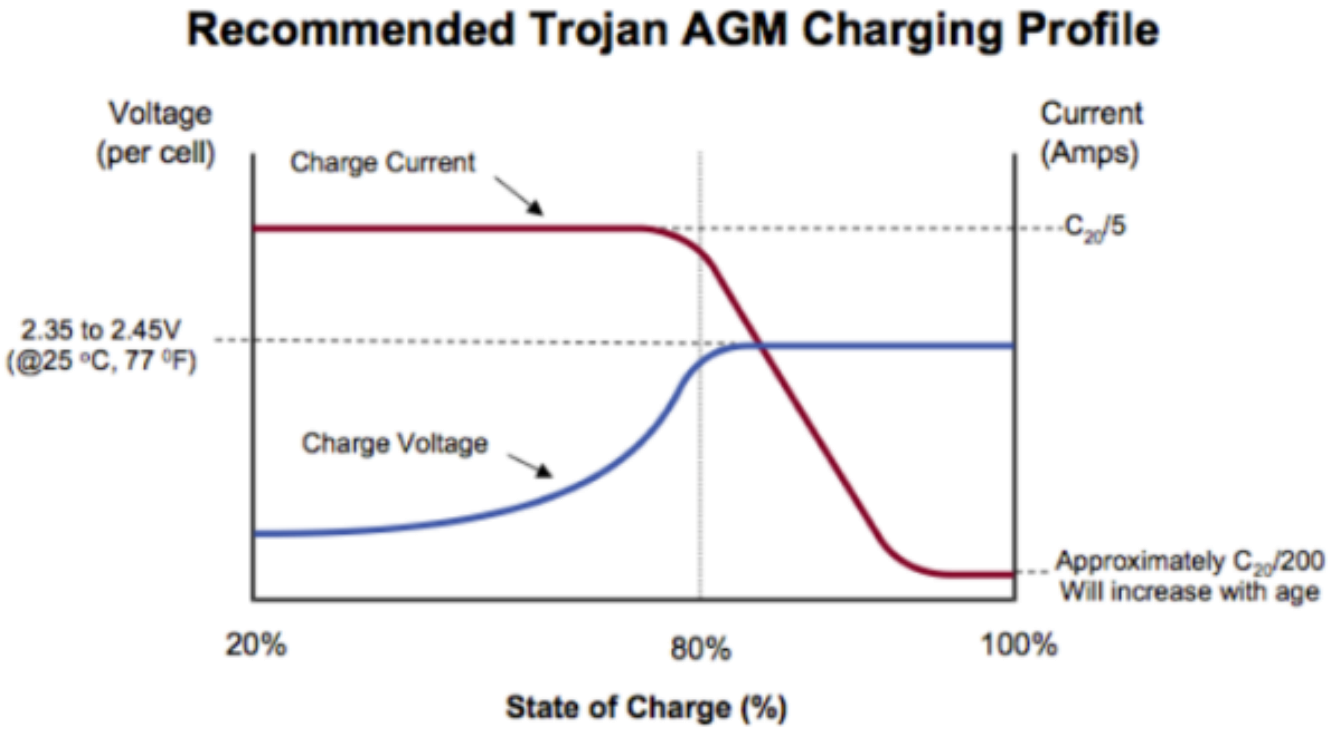
## Li-ion Cells vs Lead Acid

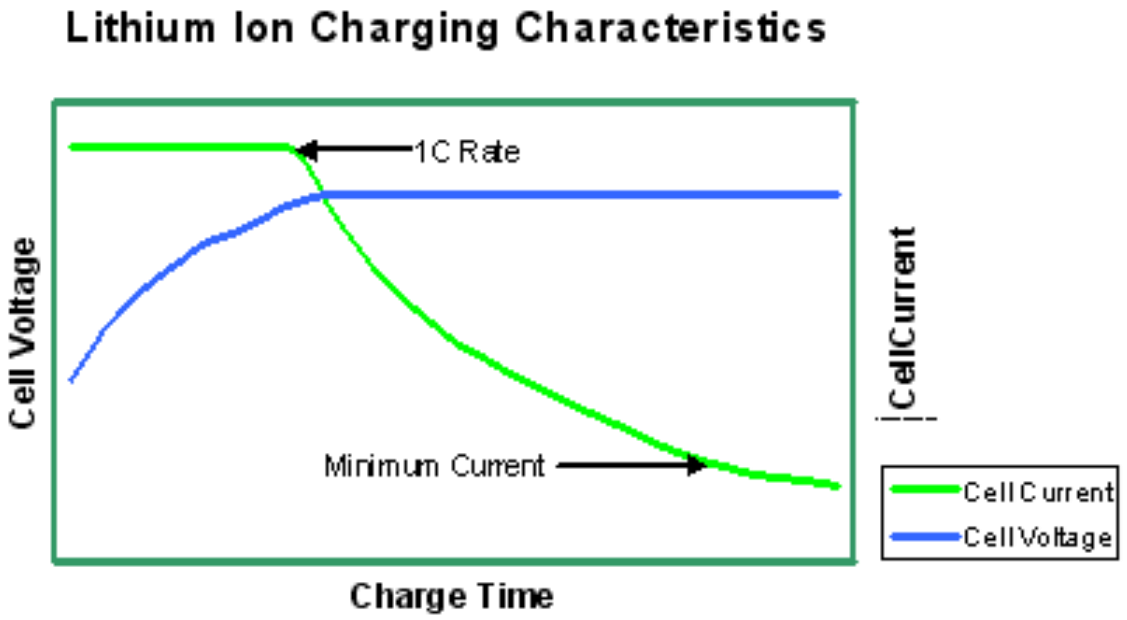


# Charging Lithium vs Lead Acid



# Lithium Terminology Glossary

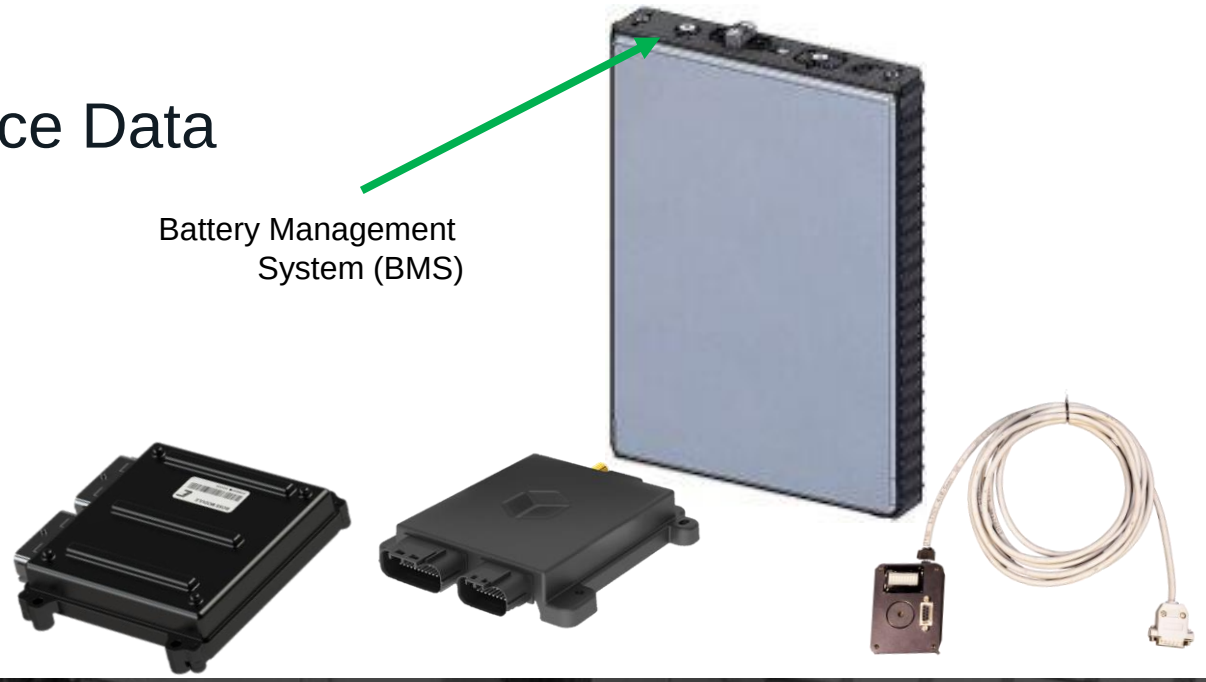
- Battery Discharge Indicator (BDI)
- State of Charge (SOC)
- Battery Management System (BMS)
- Controlled Area Network (CAN)
- Battery Cell Form Factors
- Chemistry Differences
- Definition of a Cycle
- Depth of Discharge
- Calendar/Shelf Life vs. Cycle Life
- Thermal Runaway
- Capacity (amp hours v kilowatt hours)

# Battery Discharge Indicator (BDI)

- BDI communicates the battery's state of charge
- BDI houses an on/off power button, fault indicator, and battery state of charge gauge
- This could be external or could be integrated into the truck's display

# Battery Management System (BMS)

- BMS is technology designed to oversee the battery
  - Electronic software and hardware components that are attached and govern the cells of the battery
  - This can be integrated or completely stand-alone
  - The level of sophistication varies
    - Communication of Performance Data
    - Monitors Cell Balancing
    - Voltage Limitations
    - Monitors Temperatures
    - Battery Usage



# CAN Integration (Controller Area Network)

- The battery's BMS can communicate with the truck and the charger over CAN bus
- Information provided to the truck can be displayed to inform the operator and warn the truck before any low state of charge disconnect
- Instructions to the charger can optimize the charge, allowing it to be as rapid as possible without causing an over-temperature or over-voltage condition for any cell
- Use of CAN bus increases the safety and longevity of the battery and MHE

# Battery Cell Form Factors

**Cylindrical Cells:**

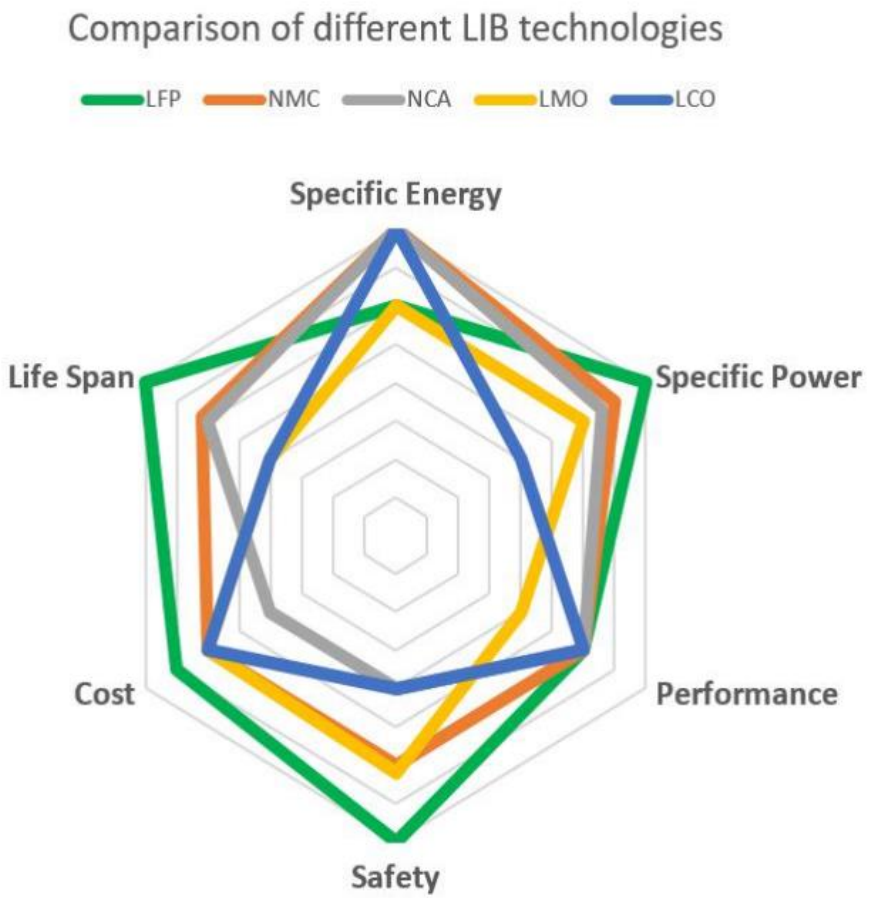
- 18650's or 26650's
- Robust, rigidly packaged cell only requiring electrical connections
- Cylindrical cells allow for design protection regardless of supplier

**Prismatic Cells:**

- Pouches  made of a thin polymer (not rigid) with terminals
- Requires a rigid structure to protect the cell either individually or in modules
- Prismatic cells typically come in larger energy density formats

# Battery Chemistries

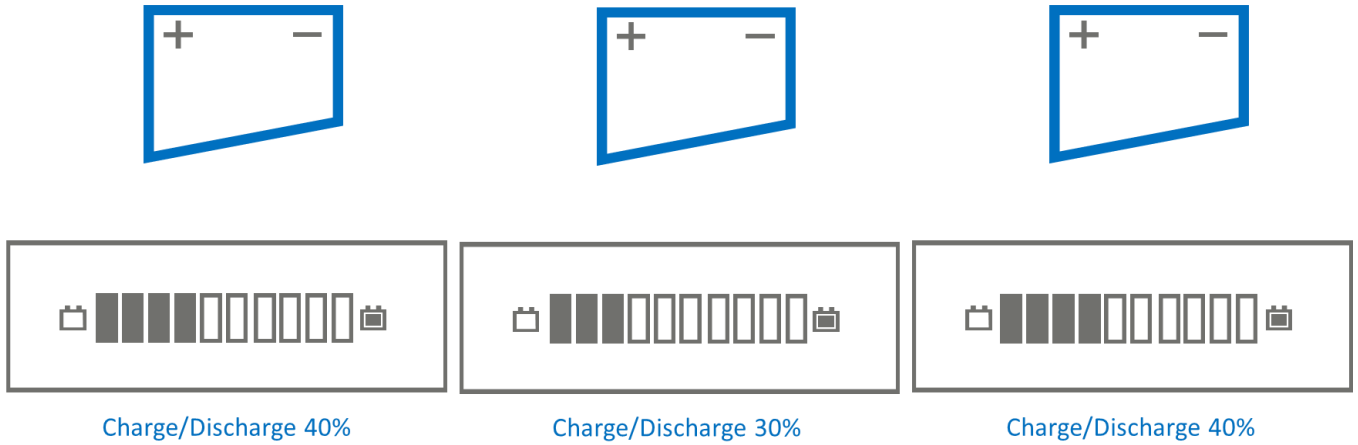
- There are many chemistry types for batteries
- We will focus on the top four:
  - **Lithium Iron Phosphate (LFP-LiFePO4)**
    - High thermal stability
    - Moderate specific energy and nominal voltage
  - **Lithium Nickel Cobalt Aluminum (NCA)**
    - High energy density
    - Poor thermal stability
  - **Lithium-Cobalt-Oxide (LCO)**
    - High specific energy
    - Short life span
  - **Lithium Nickel Manganese Cobalt Oxide (NMC)**
    - High capacity
    - Poor thermal stability




Source: www.efore.com/content/uploads/2020/12/Comparison_of_lithium_batteries_20201209.pdf

# What is a Cycle?

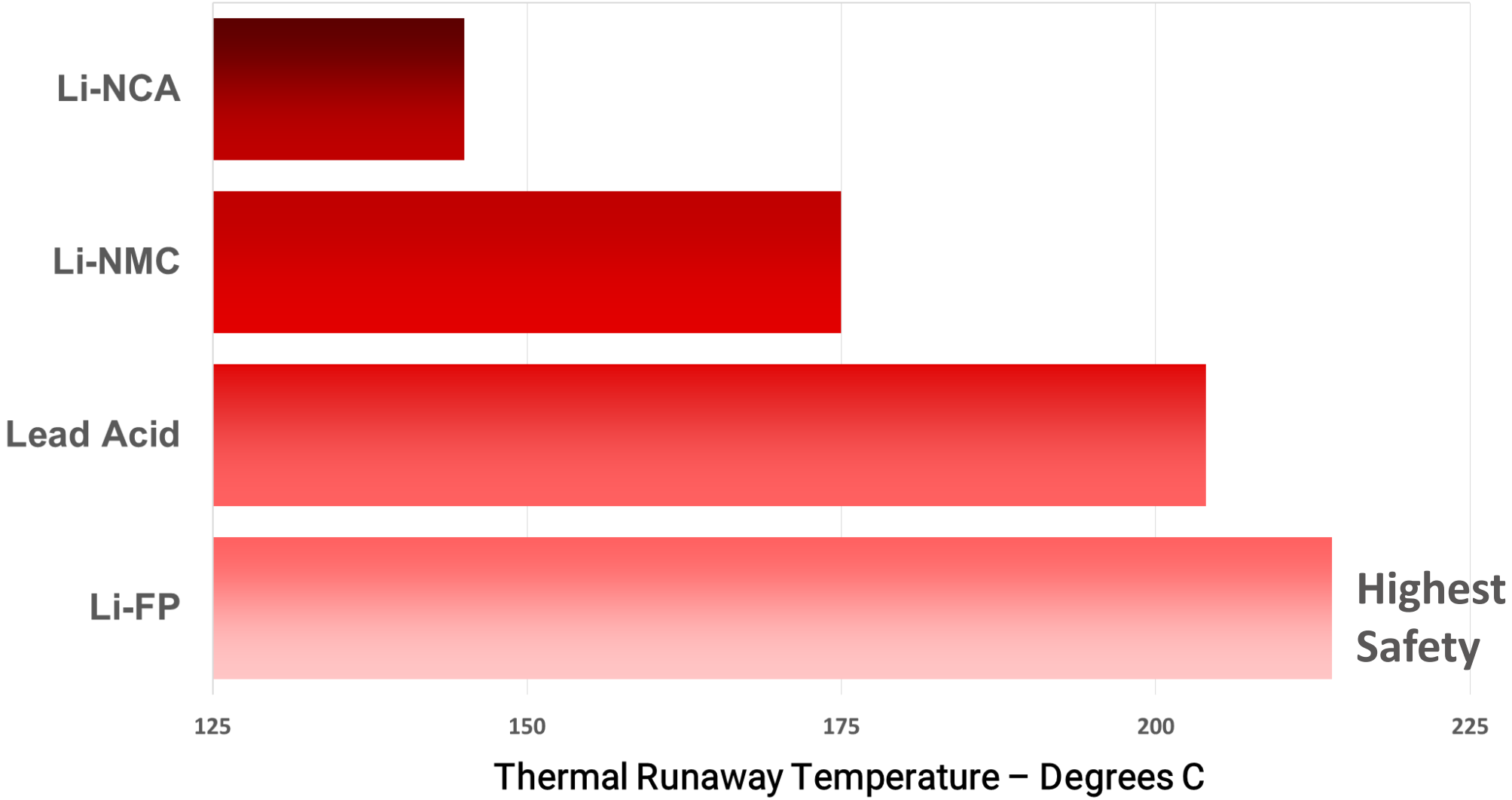
- Cycles are defined differently across companies as it pertains to warranty and longevity of the battery
  - Some companies have moved to a total amperage throughput vs defined cycle to capture regenerative braking as it pertains to a battery's capacity
  - Cycles can be defined as:
    - Discharge and charge of any amperage counts as a cycle
    - 80% depth of discharge of battery and charge back to 100% counts as a cycle
    - Cumulative charge and discharge equal to a percentage of the battery’s rated capacity regardless of depth of discharge
- Battery chemistry and depth of discharge are the most important variables when calculating a batteries cycle life



# Calendar/Shelf Life vs. Cycle Life

- Calendar life is the time for which a battery can be stored, as inactive or with minimal use, such that its capacity remains above 80% of its initial capacity
- Cycle life is the number of charge and discharge cycles that a battery can complete before losing performance
  - Within MHE; cycle life is commonly referred to as the number of defined cycles a battery can undergo before its capacity degrades to 80% of its rated capacity
  - Cycle life is impacted negatively by charging conditions, depth of discharge, and calendar life

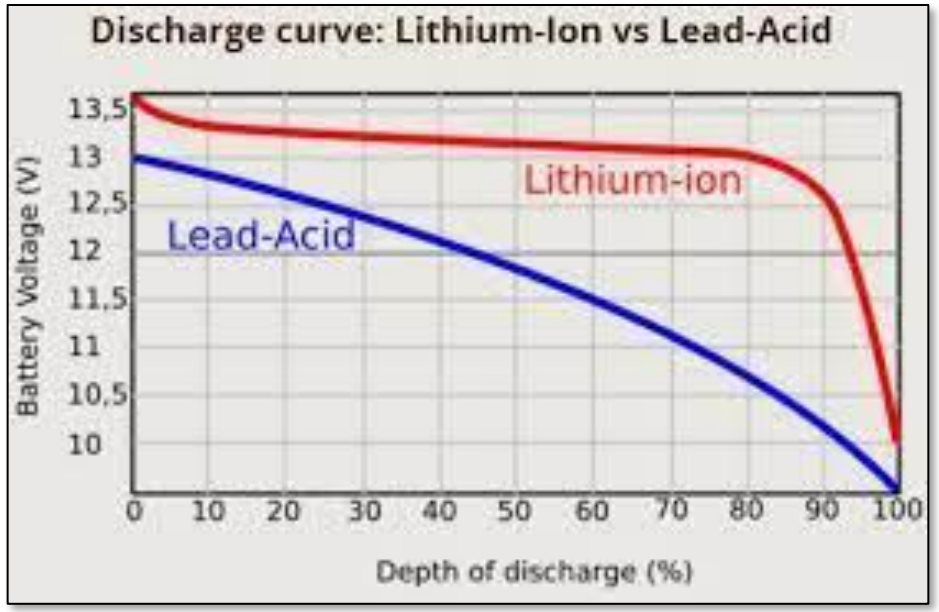
# Thermal Runaway



# Capacity (Amp Hours v. Kilowatt Hours)

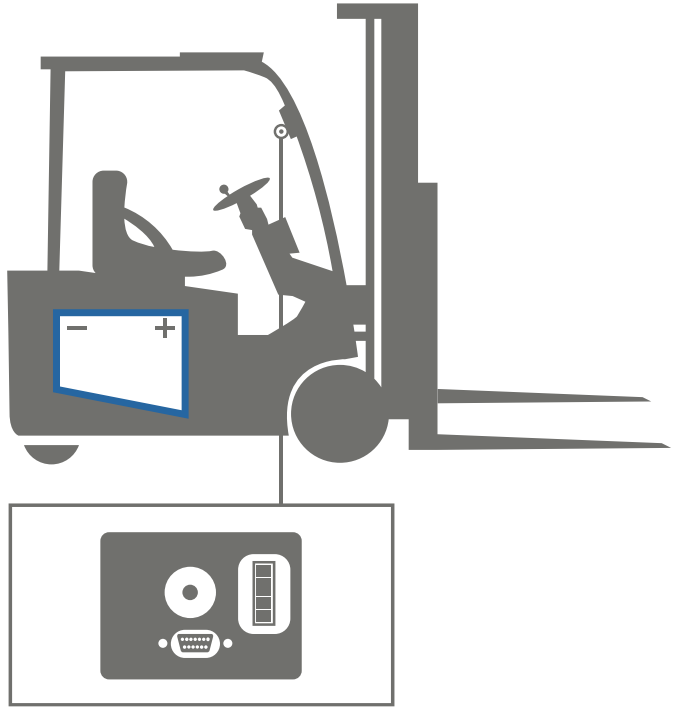
- Both are units connected with time (hours)
- Why is it important to understand the difference?
  - Voltage is a key component to calculating Amp Hours and Kilowatt Hours
  - Lithium has a higher voltage than lead acid 25.6v vs 24v
    - Resulting in a higher amp hour or kWh rating

$$kWh = \frac{Ah \times V}{1,000}$$

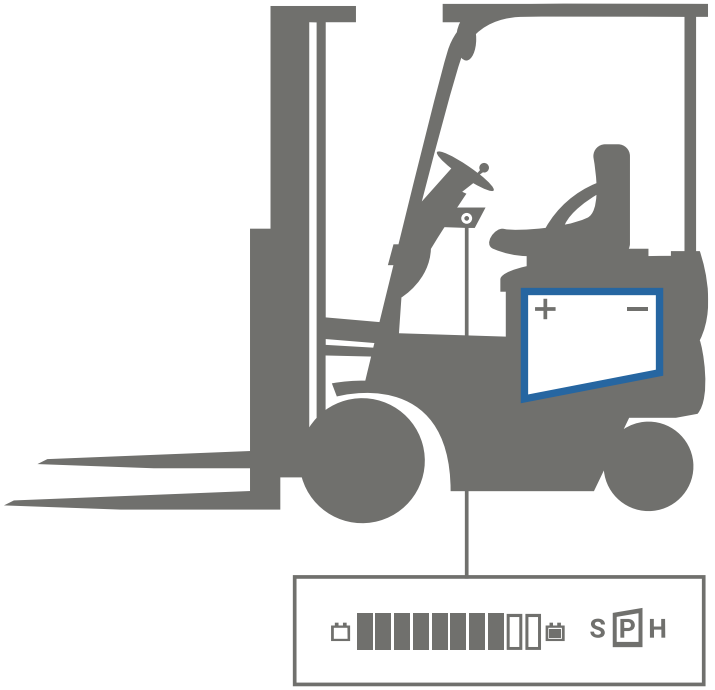



$$Ah = \frac{kWh \times 1,000}{V}$$

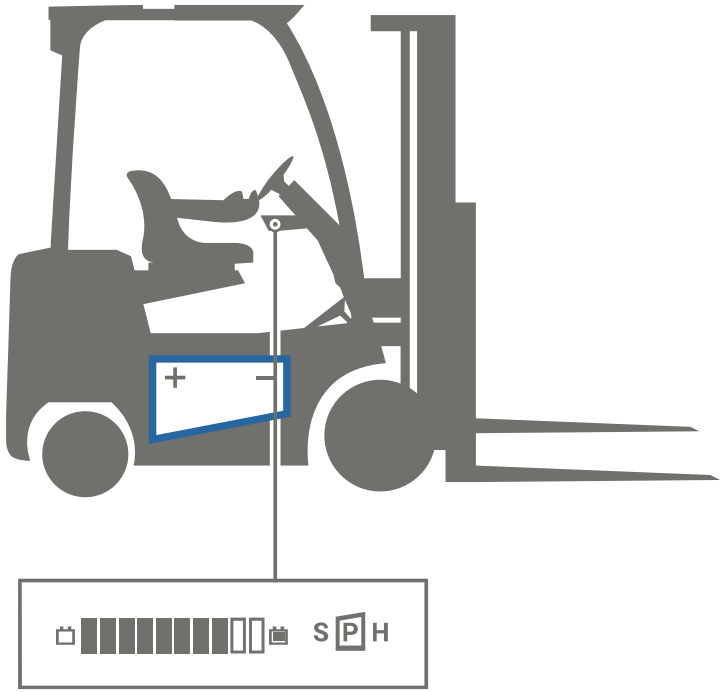
# Types of Lithium Battery Integration with Forklifts



Drop-in lithium battery with an external battery discharge indicator (BDI)

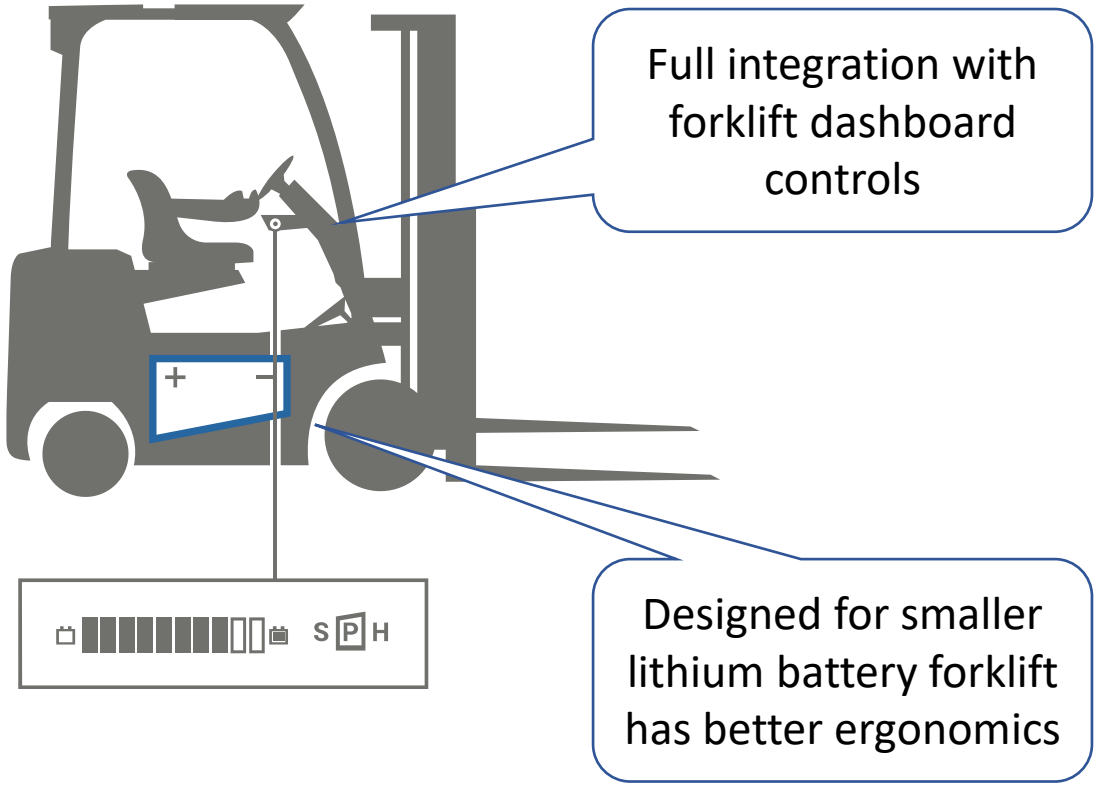



Controller Area Network (CAN) integrated drop-in lithium battery



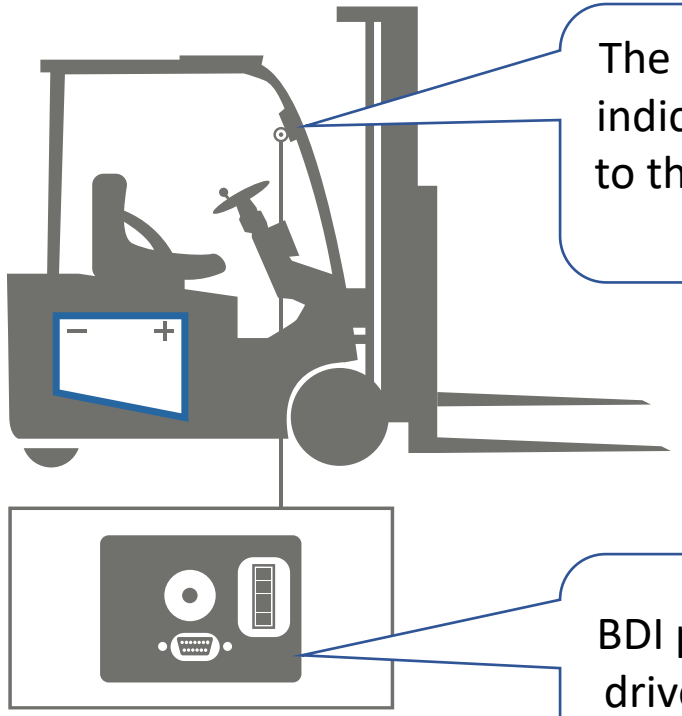

Chassis-integrated lithium battery

# Chassis-integrated lithium battery



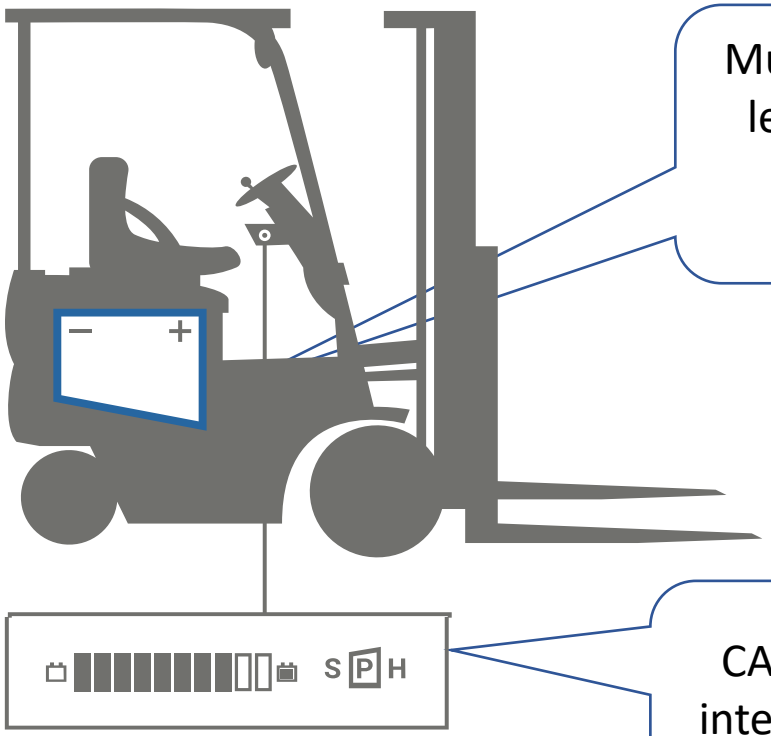

- Better ergonomics (more room in the cabin, lower center of gravity)
- Forklift – battery – charger system is CAN integrated; unified warranty
- Significantly higher cost compared to a similar drop-in battery
- Narrow product line, no flexibility in battery Ah capacity or upgrade packages (sealed, cold storage, etc.)

# Drop-in lithium battery with an external battery discharge indicator (BDI)




- Easy replacement of a lead-acid battery, plug-and-play solution
- The external battery discharge indicator provides all key signals for the driver
- Cost-efficient
- Full range of battery options and upgrades
- No integration with the forklift dashboard controls

# Controller Area Network (CAN) integrated drop-in lithium battery




- Full integration with the truck dashboard controls
- Full range of Ah capacity battery options and upgrades for cold storage, outdoor use, etc.
- Cost-efficient
- Both truck and battery retain dollar value for second life use

# Choice Benefits the Truck Buyers

- Lithium technology can provide an optimum battery setup for specific applications of forklifts
  - flexibility in Ah capacity
  - options and upgrades
- Direct and seamless integration with forklift controls through CAN improves the efficiency and safety of operations
- Smaller battery compartment and lower center of gravity improve forklift design

Forklift and lithium battery manufacturers need to develop unified standards for CAN connection protocols.
Customers will have a better choice of customizable equipment and improved efficiency and safety.

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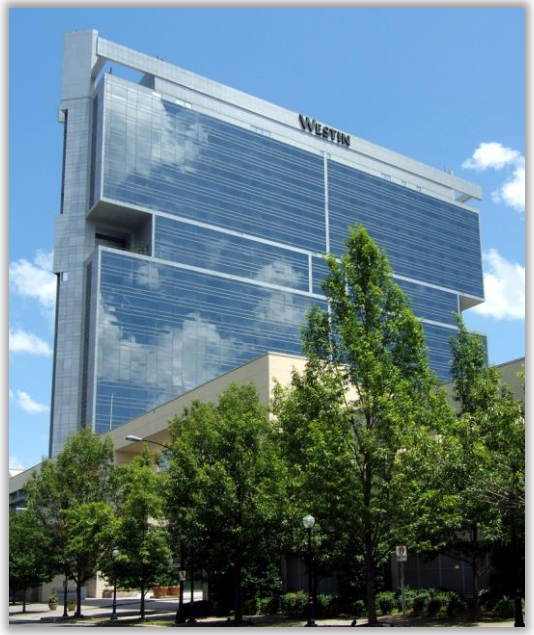
# Upcoming Meetings




**2023 Spring Meeting**

May 21 - 24, 2023

The Westin Hotel,

Charlotte, NC

**2023 Annual Meeting**

October 1 - 4, 2023

Diplomat Beach Resort

Fort Lauderdale, FL

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# Questions?

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