Lithium Ion Batteries for Stationary Applications

IEEE Presentaion
Dan Youngs 2020

Agenda

1. Saft Overview
2. Lithium Technology
3. Battery Comparison
4. Typical Systems
5. Building Codes

1 SAFT OVERVIEW

Serving Multiple Customer Segments

Industrial Standby


Schneider Electric
AEG

Aviation


AIRBUS
BOEING

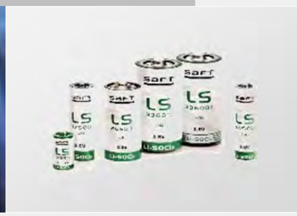
Rail


ALSTOM
BOMBARDIER

Telecom


at&t
Reliance Jio Infocomm

Civil Electronics

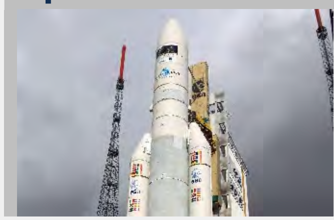



Landis+Gyr manage energy better
Itron

Defence

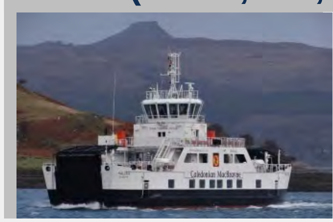

Liberté • Égalité • Fraternité
RÉPUBLIQUE FRANÇAISE
MINISTÈRE DE LA DÉFENSE

Space




THALES
LOCKHEED MARTIN

Other (Marine, Grid, Vehicles)




Imtech MARINE

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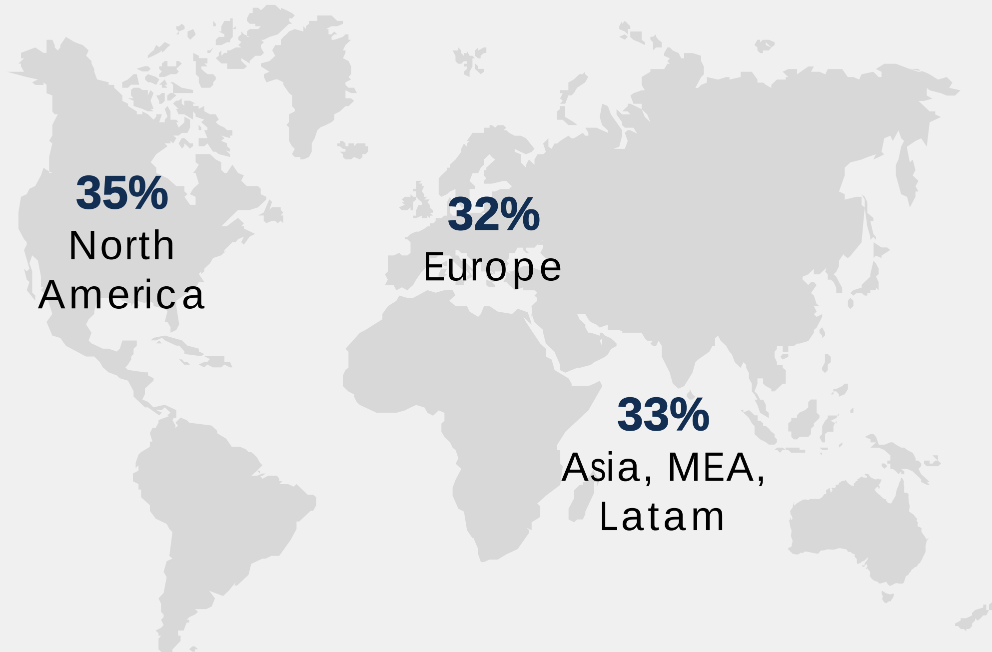
Saft: A Company of TOTAL Group

SAFT DEVELOPS AND MANUFACTURES ADVANCED-TECHNOLOGY BATTERY SOLUTIONS

FOR MULTIPLE APPLICATIONS

- **Diversified** base of industries
- **Broad portfolio of technologies** (Ni-based, Primary Lithium and Lithium-ion)
- **Leadership positions on 75-80%** of revenue base (Industrial Standby, Metering, Aviation, Rail, Defense, Satellites)

ON A GLOBAL SCALE



*** SAFT is part of TOTAL new division, "Gas, Renewables & Power", since September 1st, 2016**

~100	$921	9%	+4,100	+3,000
years of history	revenue FY 2017	invested in R&D	people	customers

A Strong International Presence

- Head office
- Manufacturing sites
- Sales offices

14 manufacturing sites

19 countries

31 sales offices

2 LITHIUM-ION TECHNOLOGY

IEEE Guide for Lithium Ion 1679.1

– Recommended reading on Lithium Ion Battery systems

IEEE STANDARDS ASSOCIATION IEEE

IEEE Guide for the Characterization and Evaluation of Lithium-Based Batteries in Stationary Applications

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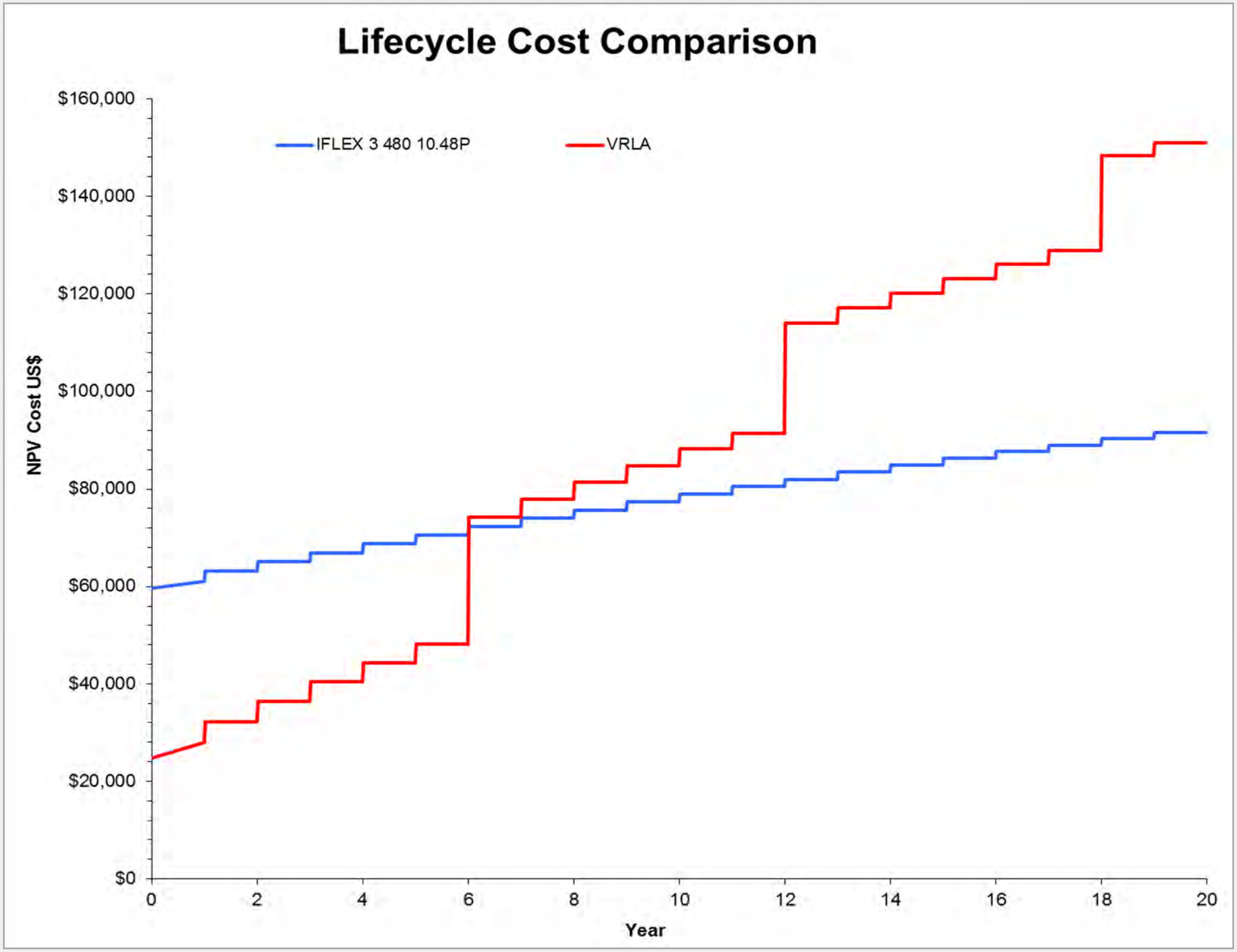
Why Lithium?

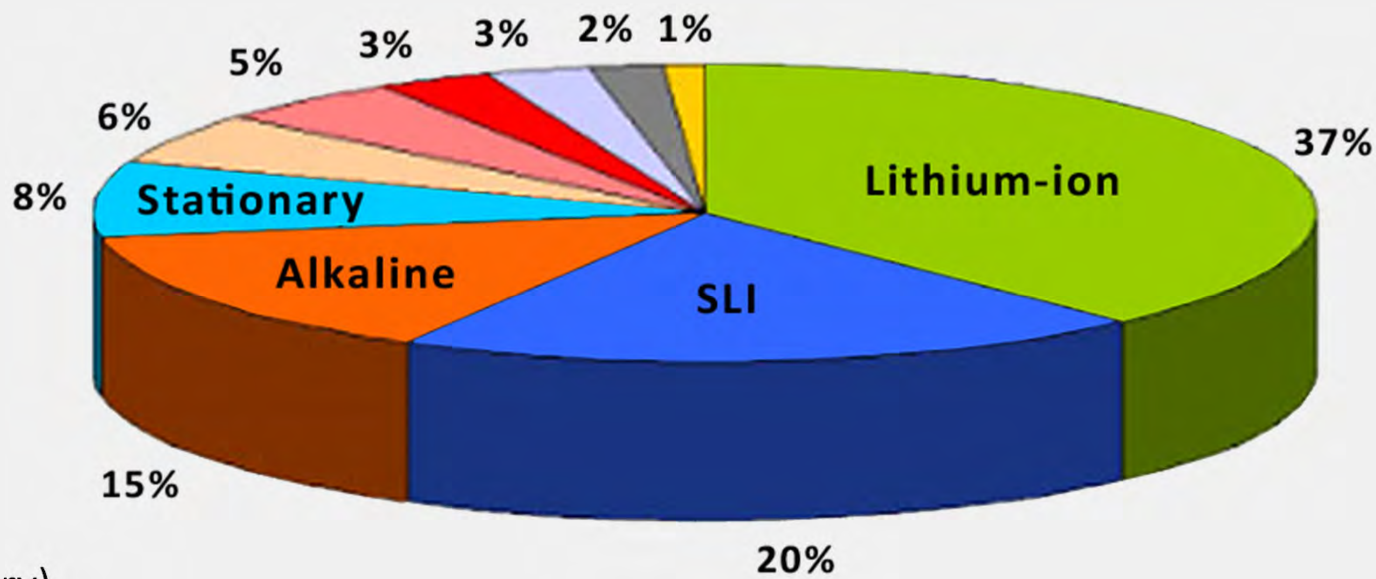
- Lighter
- Smaller footprint
- Higher Efficiency
- Faster recharge
- More Cycles
- Longer Life
- Lower total cost of ownership
- Integrated supervision
- Less Maintenance

Why Lithium?


Lifecycle Cost Comparison
IFLEX 3 480 10.48P
VRLA
NPV Cost US$
$160,000
$140,000
$120,000
$100,000
$80,000
$60,000
$40,000
$20,000
$0
0
2
4
6
8
10
12
14
16
18
20
Year

Why Lithium?

Global Market Adoption – 2009

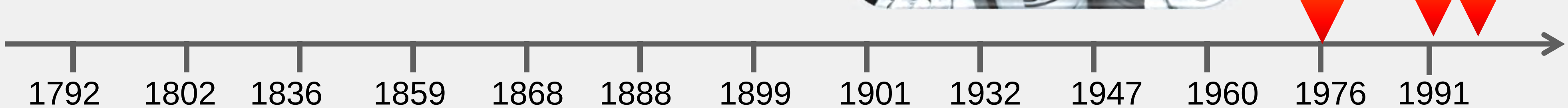


- 37% Lithium-ion
- 20% Lead-acid (SLI)
- 15% Alkaline (Primary)
- 8% Lead-acid (Stationary)
- 6% Zinc-carbon (Primary)
- 5% Lead-acid (deep-cycle)
- 3% Nickel Metal-Hydride
- 2% Lithium (Primary)
- 1% Others

Source: Frost & Sullivan (2009)

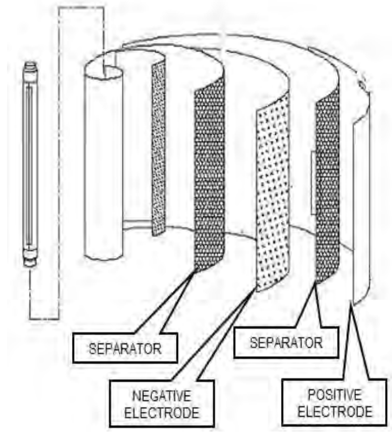
Li-ion History

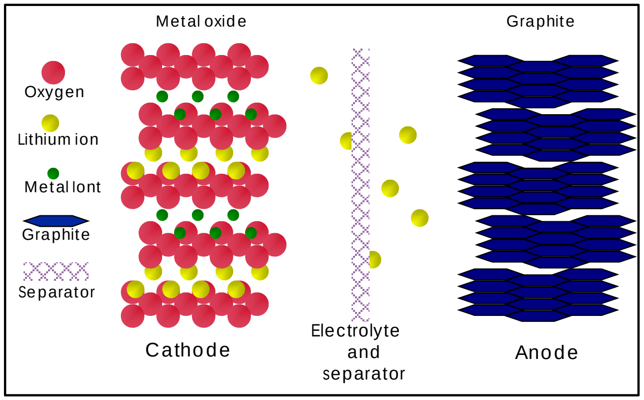
- 1976 – Exxon researcher M.S. Whittingham describes Li-ion concept in Science publication entitled, “Electrical Energy Storage and Intercalation Chemistry.”
- 1991 - SONY introduced the first Li-ion 18650 cell
- 1992 - Saft introduced Li-ion to the market
  - Large format was introduced in 1995



Li-ion Cell Construction

- Al foil is used as the current collector for the positive electrode.
- Cu or Al foil is used as the current collector for the negative electrode.
  - Typical Li-ion Chemistry:
    - Positive – Lithiated Metal Oxide or Phosphate
    - Negative – Graphite
    - Electrolyte - LiPF6 salt dissolved in a mixture of organic solvents
    - Separator – Micro porous polyolefin
  - Can or Pouch enclosure

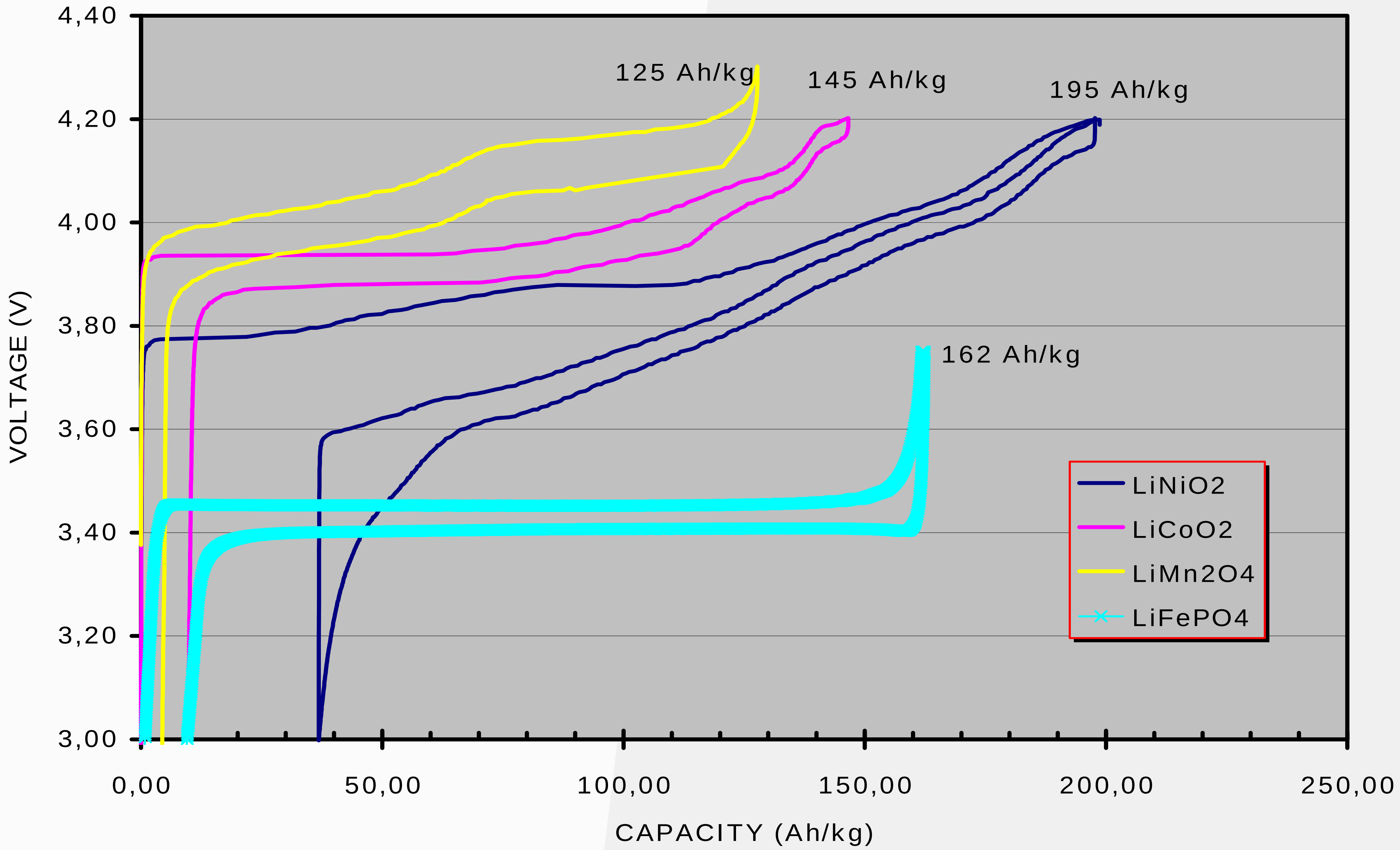




Li-ion: Many Flavors

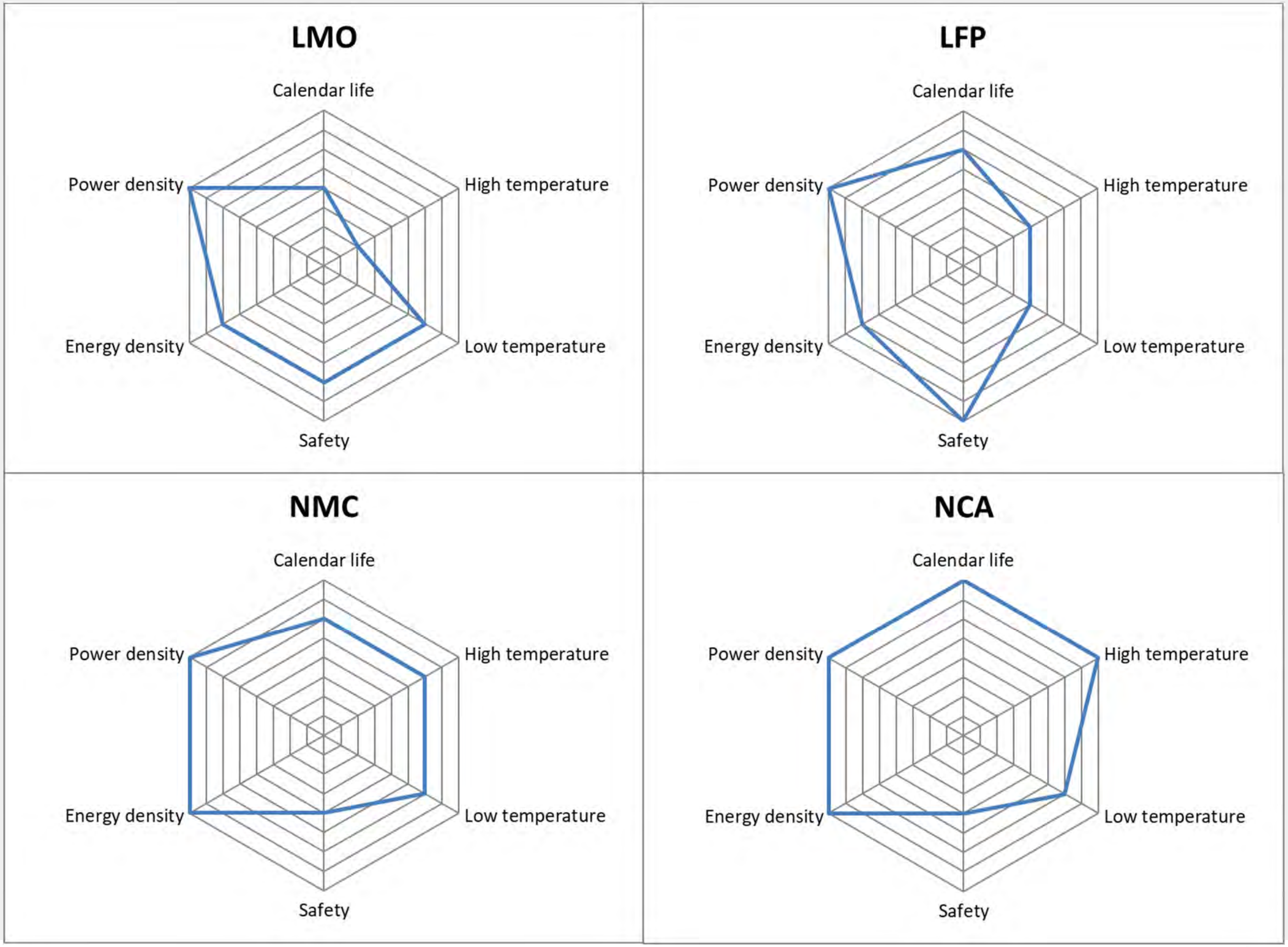
- Commonly Used Cathodes
  - $LiCoO_2$ = LCO – Cell Phones, Tablets, Cameras
  - $LiNiCoAlO_2$ = NCA – Industrial, EV's
  - $LiNiMnCoO_2$ = NMC – E-bikes, Medical Devices, EV's
  - $LiMn_2O_4$ = LMO – Power Tools, Medical Devices
  - $LiFePO_4$ = LFP – Portable & Stationary, high load applications
- Commonly Used Anode
  - Graphite = Carbon (C)
- Emerging anodes
  - $Li_4Ti_5O_{12}$ = LTO - Lithium Titanate Oxide
  - Alloy anodes = Si and Sn based (Silicon and Tin)

Charging curves of Li-ion



Major Lithium-ion Chemistries

Tradeoffs among the four principal lithium ion battery chemistries



Source: Battcon Paper J.McDowall

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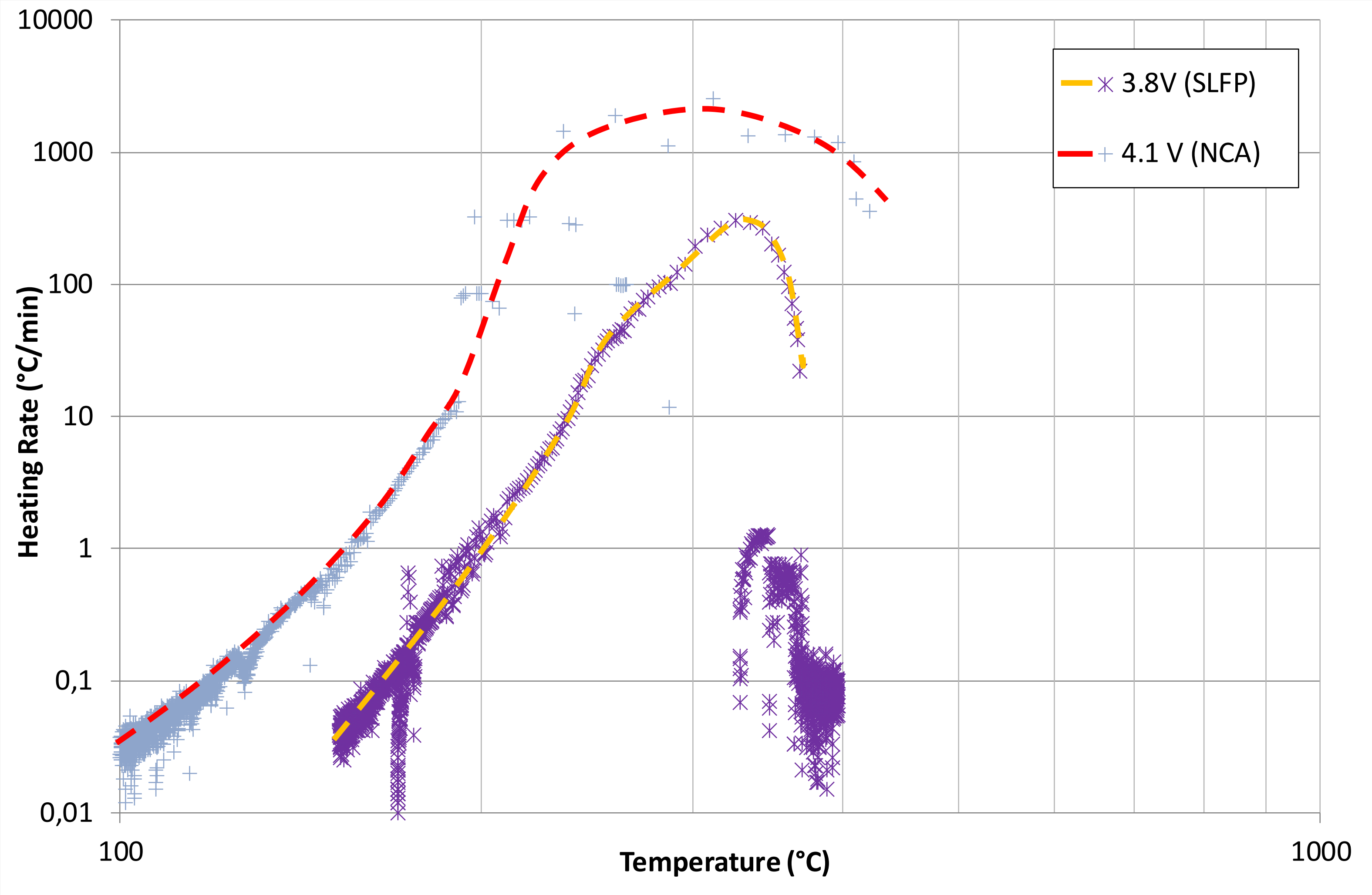
Thermal Runaway comparison NCA vs LFP



– Comparison of oxyde based NCA and LFP technologies in Accelerated Rate Calorimetry

– One order of magnitude less heat release rate for LFP

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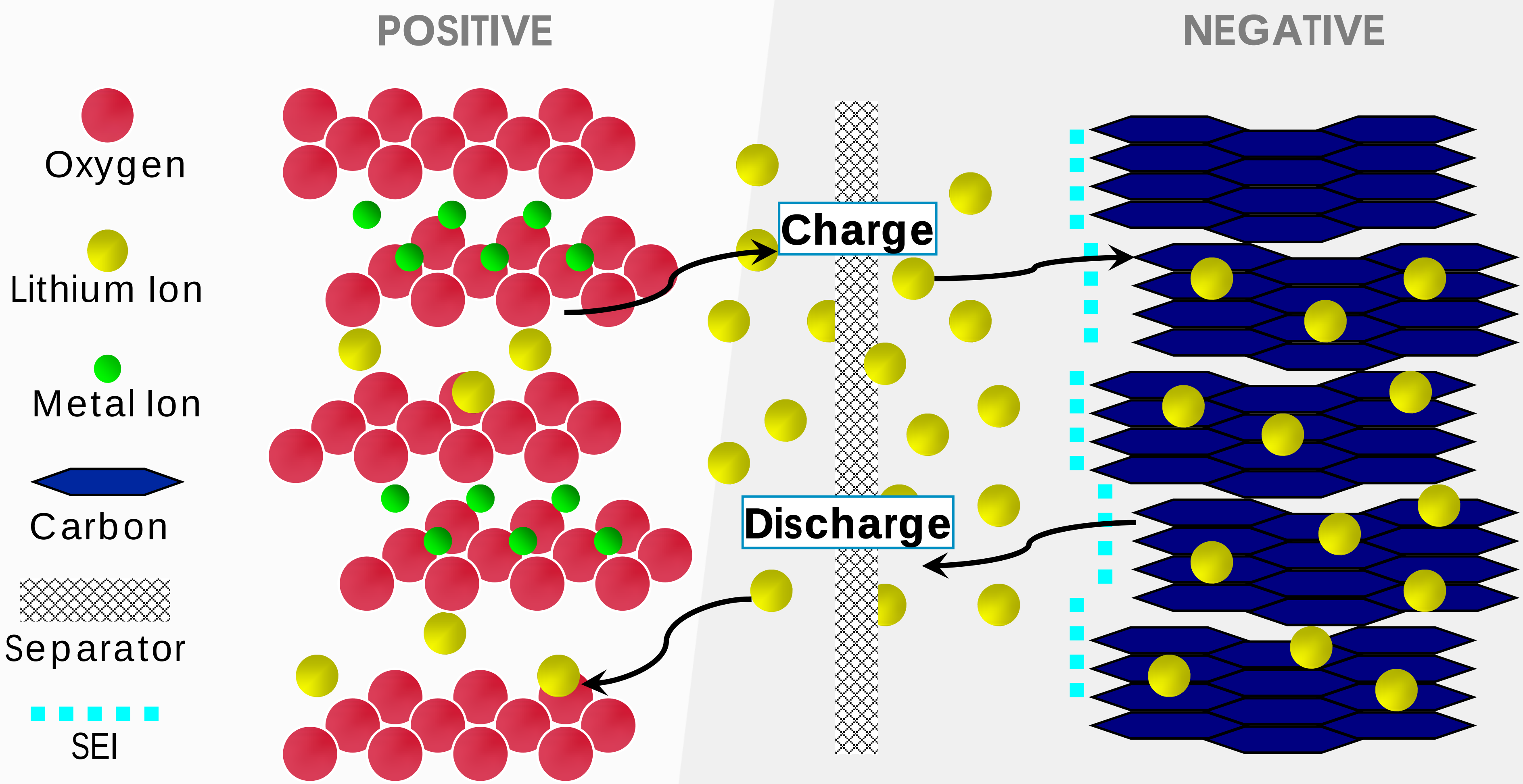
Intercalation & Reaction mechanism Carbon Anode



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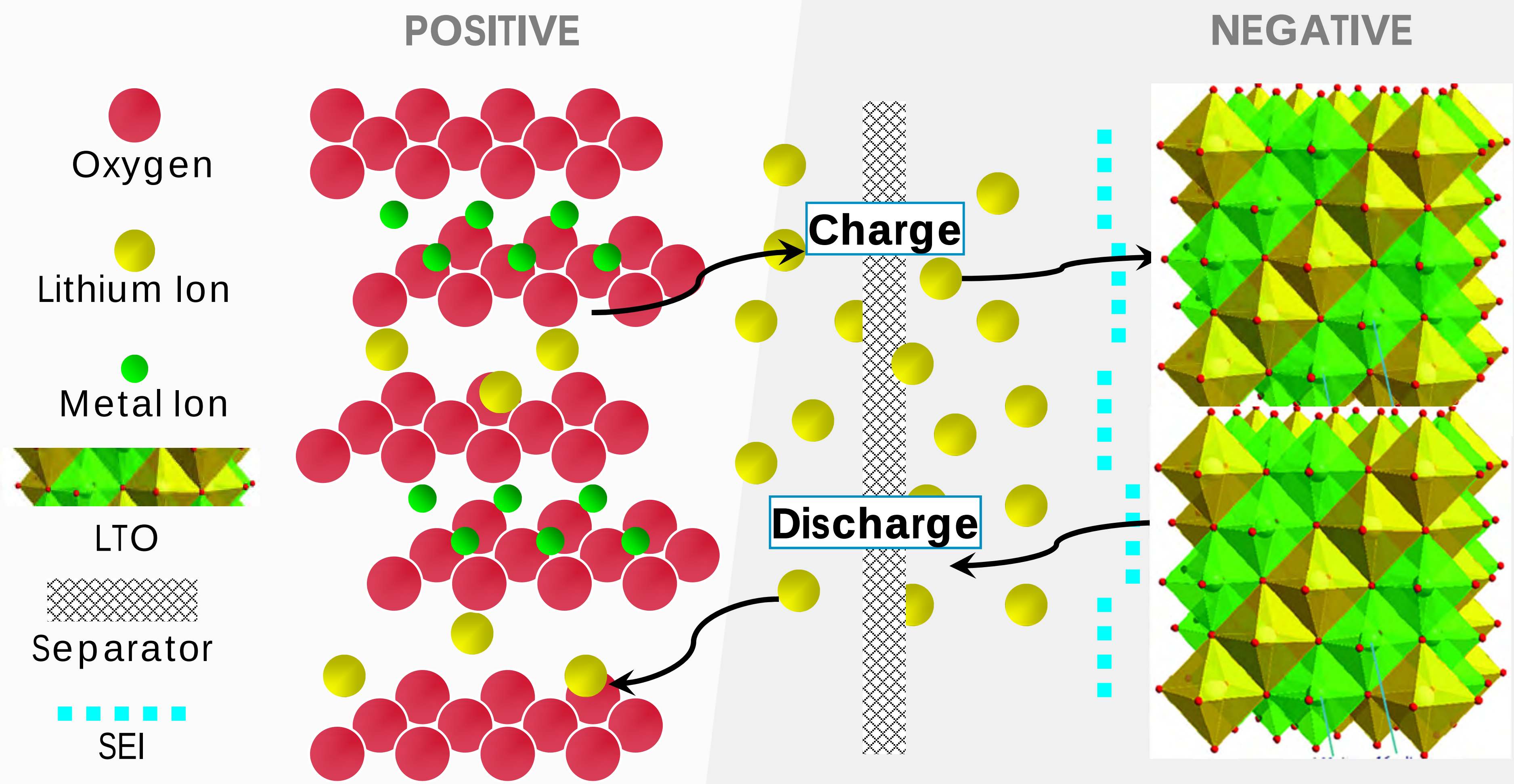
Intercalation & Reaction mechanism LTO Anode



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Power to Energy Ratio

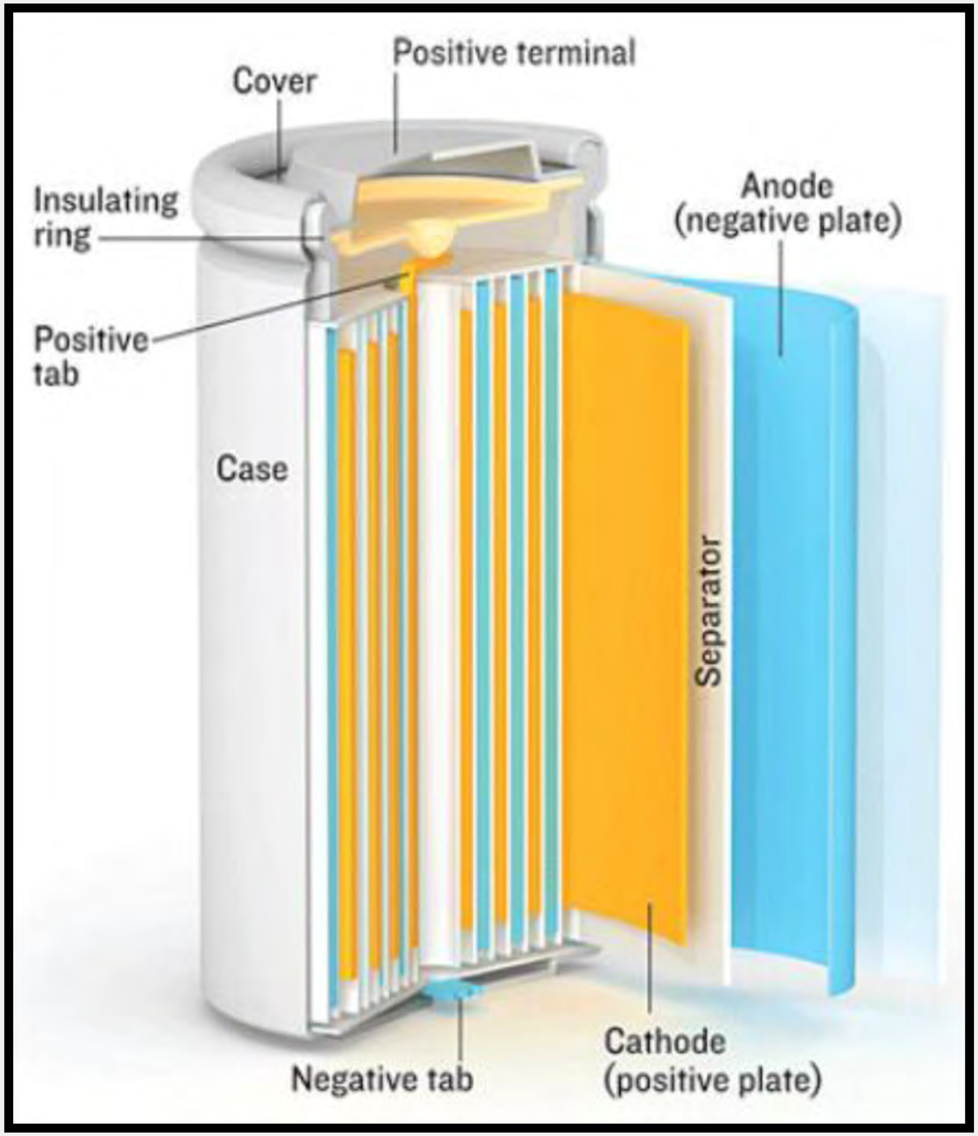
There is always a trade off between Power and Energy

Power Cell

- More current carrying material
- Less active material

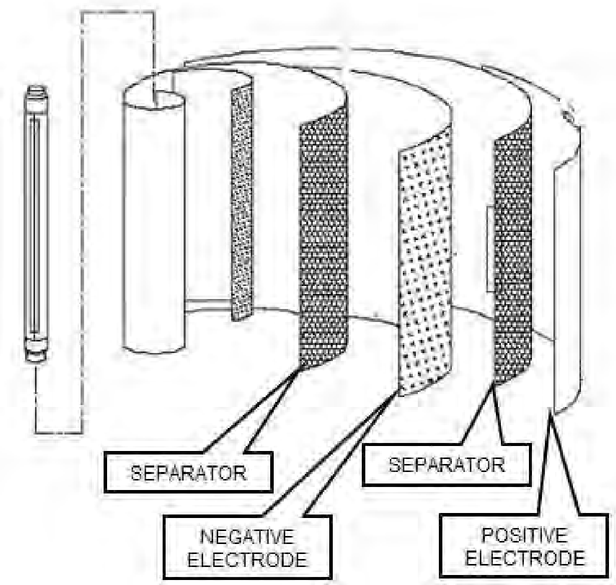
Energy Cell

- Less current carrying material
- More active material



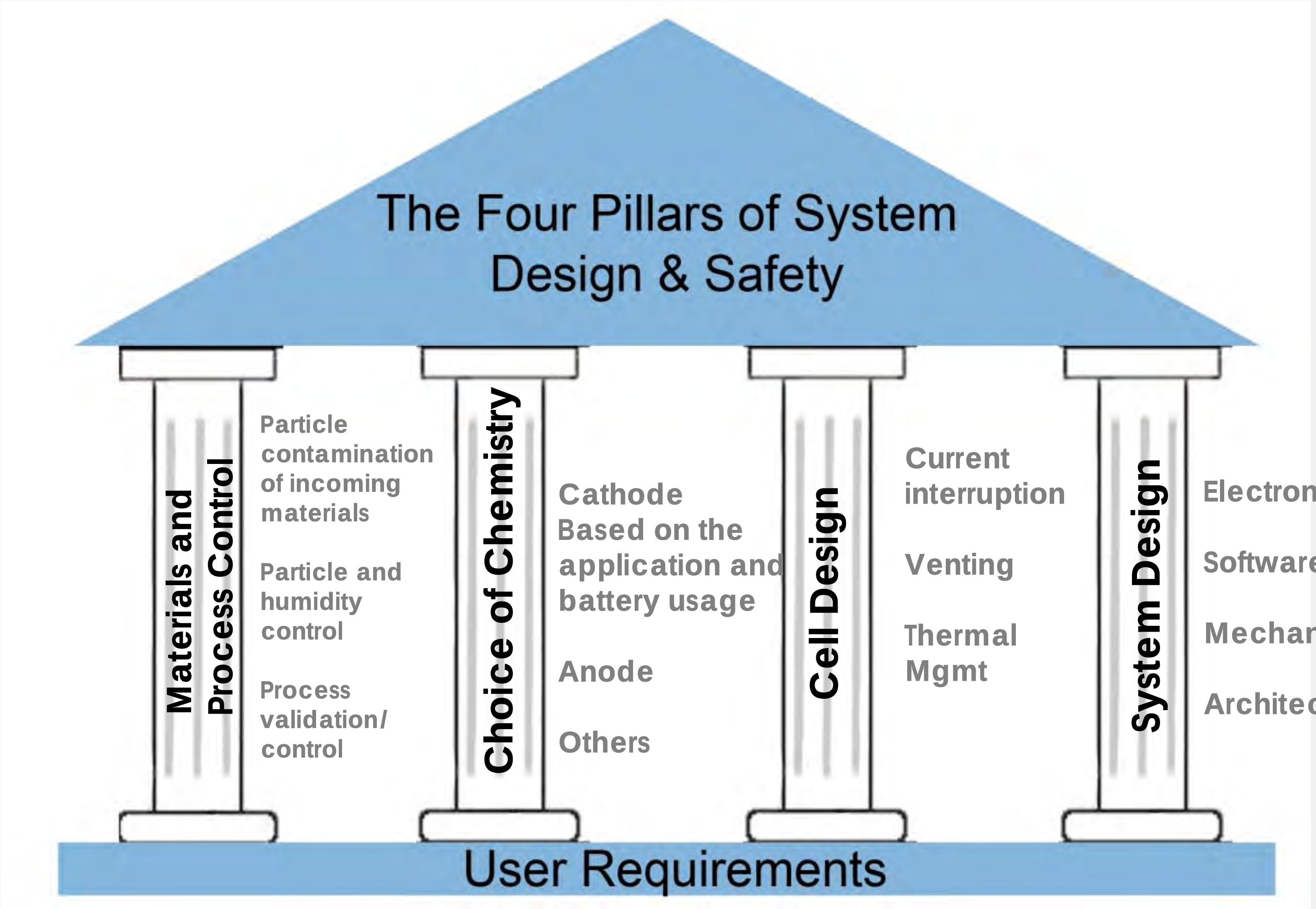
Cell Formats

- **Cylindrical**
  - Provides best support for expansion and contraction of electrodes during cycling
  - Less factory handling required
  - Easier to have space between cells
- **Prismatic**
  - Better energy density at system level
    - Stacked, Z-fold or Wound
  - Can be spaced very closely together
- **Pouch**
  - Requires well defined module construction



LIB Safety - A System design Approach

Four critical pillars of safety



Main Functions of the Battery Management System

- Short circuit & over current protection
- Overheating protection
  - Charging or discharging stopped if module temperature >70°C
- Overcharge protection
  - Charge stopped if a cell reaches maximum voltage value
- Charge protection after an over discharge
  - Recharge mode is prevented if a cell is over discharge

3 BATTERY COMPARISON

Technology Physical Comparison

What to look for:

- Technologies being compared
  - Li-ion Vs Nickel-Cadmium Vs Flooded Lead-Acid (VLA)
- Sizing Results
- Comparison parameters
  - Footprint
  - Volume
  - Total weight (battery + racking)
  - Price

Sizing Parameters - Typical Switchgear Battery

Parameters	
Min. Voltage:	105 Vdc
Max. Voltage:	140 Vdc
Nom. Voltage:	125 Vdc
Design Margin:	1.15
Aging Factor:	1.25
Temperature (max):	30 °C
Temperature (min):	15 °C

Load Profile

Step	Load	Duration
1:	5 A	8hr
2:	300 A	1 min*

**For Lithium-ion and Nickel-Cadmium technologies the minimum performance step is 1 sec Vs. 1 min for Lead-Acid (Coup de Fouet).*
The "tripping load" can occur in under one second bursts.

Sizing Results

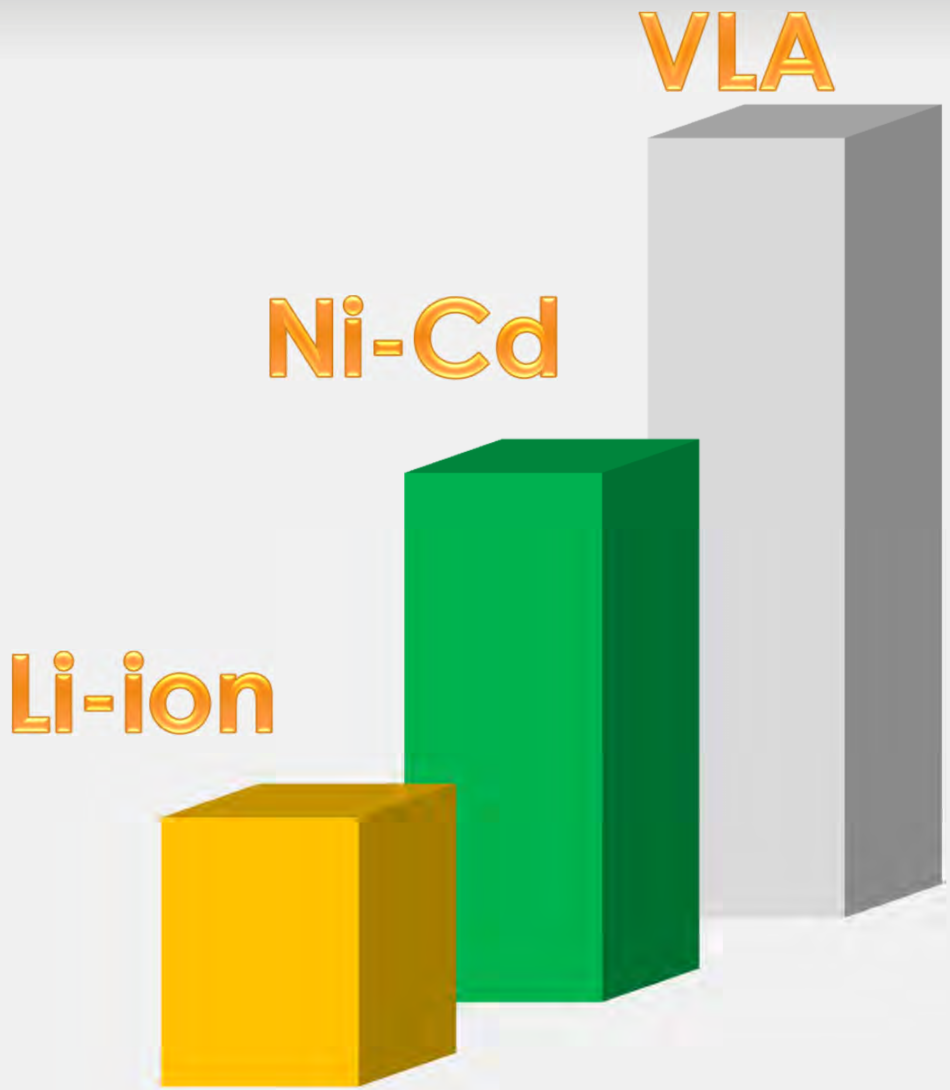
	Li-ion		Ni-Cd		VLA (LSe Range)
Nominal Capacity:	156 Ah (45% reserve capacty)	Nominal Capacity:	130 Ah	Nominal Capacity:	350Ah
No. of Strings:	2	No. of Strings:	1	No. of Strings:	1
Total WxDxH	24" x 20" x 93“	Total WxDxH	59" x 28" x 68"	Total WxDxH	83" x 28” x 71"
Total Weight:	~965 lbs	Total Weight:	~1,652 lbs	Total Weight:	~4,461 lbs
Installed Energy:	19.5 kWh (12.7 kWh needed)	Installed Energy:	16.3 kWh	Installed Energy:	43.8 kWh

Footprint Comparison

Technology	W (in)	D (in)	Area (in^2)
Li-ion	24	20	480
Ni-Cd	59	28	1,652
VLA	83	28	2,324

Volume Comparison

Technology	W (in)	D (in)	H (in)
Li-ion	24	20	93
Ni-Cd	59	28	68
VLA	83	28	71



Total Weight Comparison

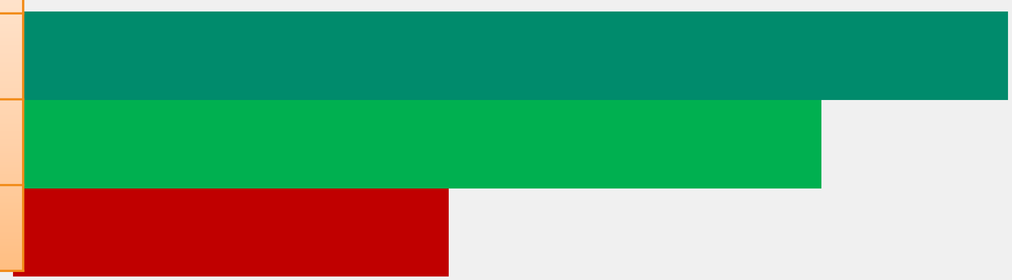
Technology	Weight (lbs)
Li-ion	965
Ni-Cd	1,652
VLA	4,461

Ni-Cd

Li-ion

Price Comparison

Technology	Initial Price
Li-ion	$32k
Ni-Cd	$26k
VLA	$14k



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TYPICAL SYSTEMS GRID

Modular systems – building blocks

- 24V or 48V modules
  - 14 cells 2P7S or 1P14S
  - 19-inch rack-mountable
- Series strings up to 1000V
  - With Battery Management Module (BMM)
- Parallel strings to meet power / energy requirements
  - With Master Battery Management Module (MBMM)
- Flexibility to fine-tune system to meet application needs

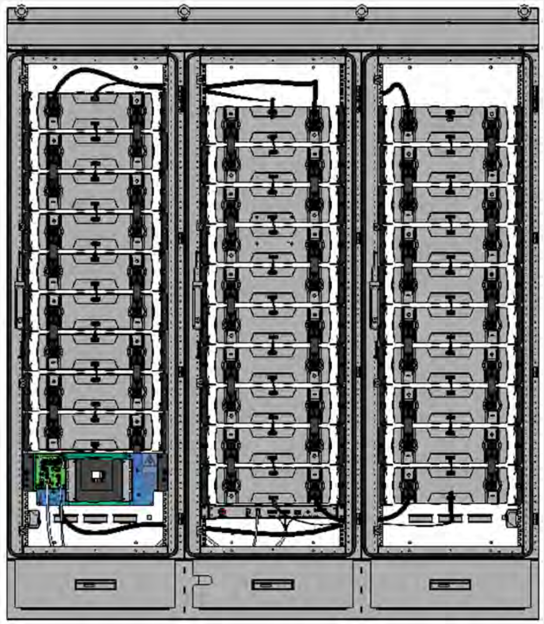
Small Containerized Systems

– Flexible power-to-energy ratio

	Energy	Medium	Power
Power (kW)	235	270	350
Energy (kWh)	123	112	80

– Main characteristics

- IP55 rated enclosure
- DC Voltage window : 790V – 588V
- HVAC or Heat Exchanger option
- Integrated fire suppression
- Distribution Cabinet



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Large Containerized System

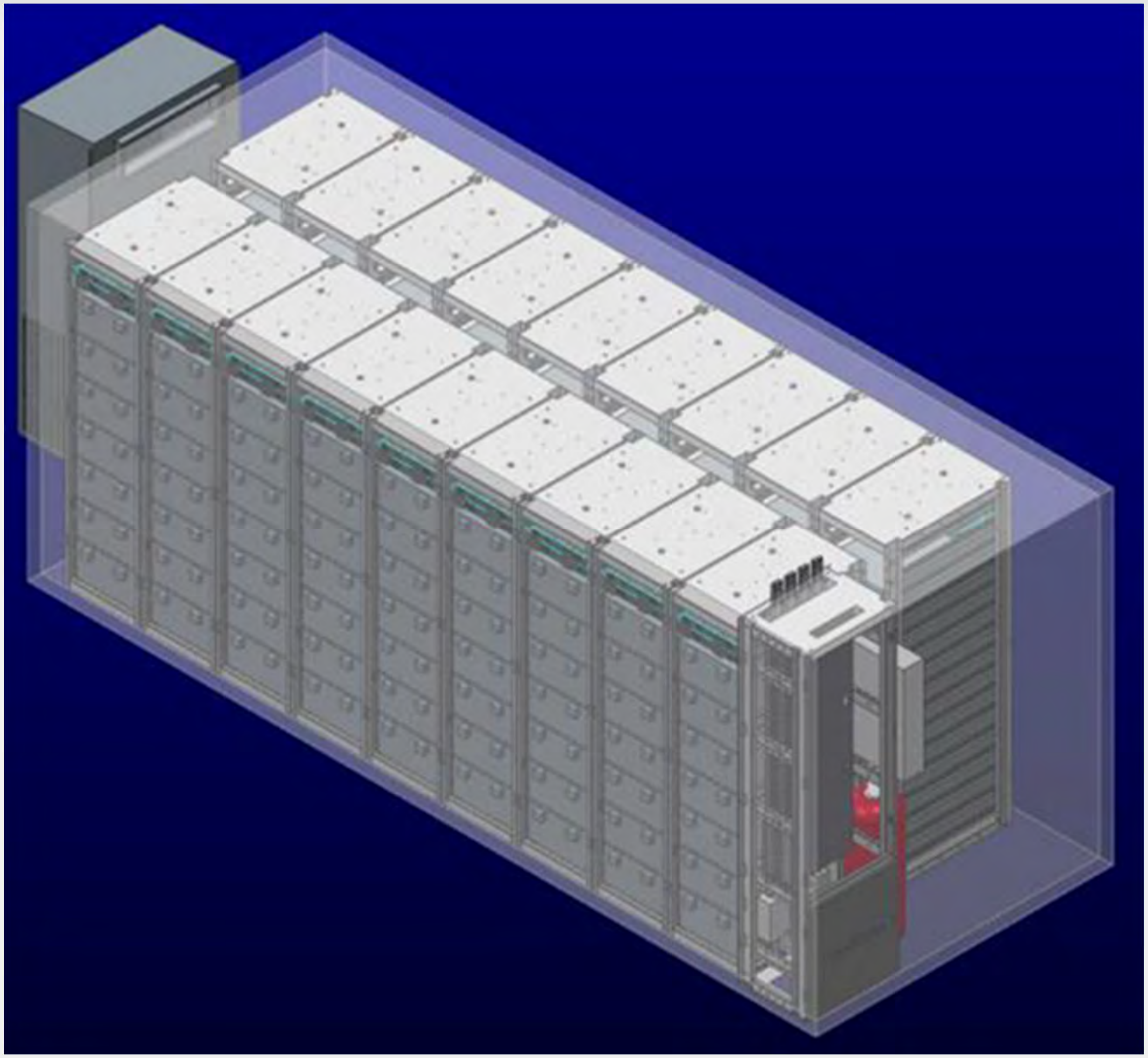
- Flexible power-to-energy ratio

	Energy	Medium	Power
Power (kW)	1000	2000	2000*
Energy (kWh)	1020	950	690

- Solar
- Wind
- Grid Services
- Transportation fully assembled

High Energy Container

- 2300 kWh
- 1000 kW discharge
- 1000v
- 20 ft container



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TYPICAL SYSTEMS INDUSTRIAL STANDBY

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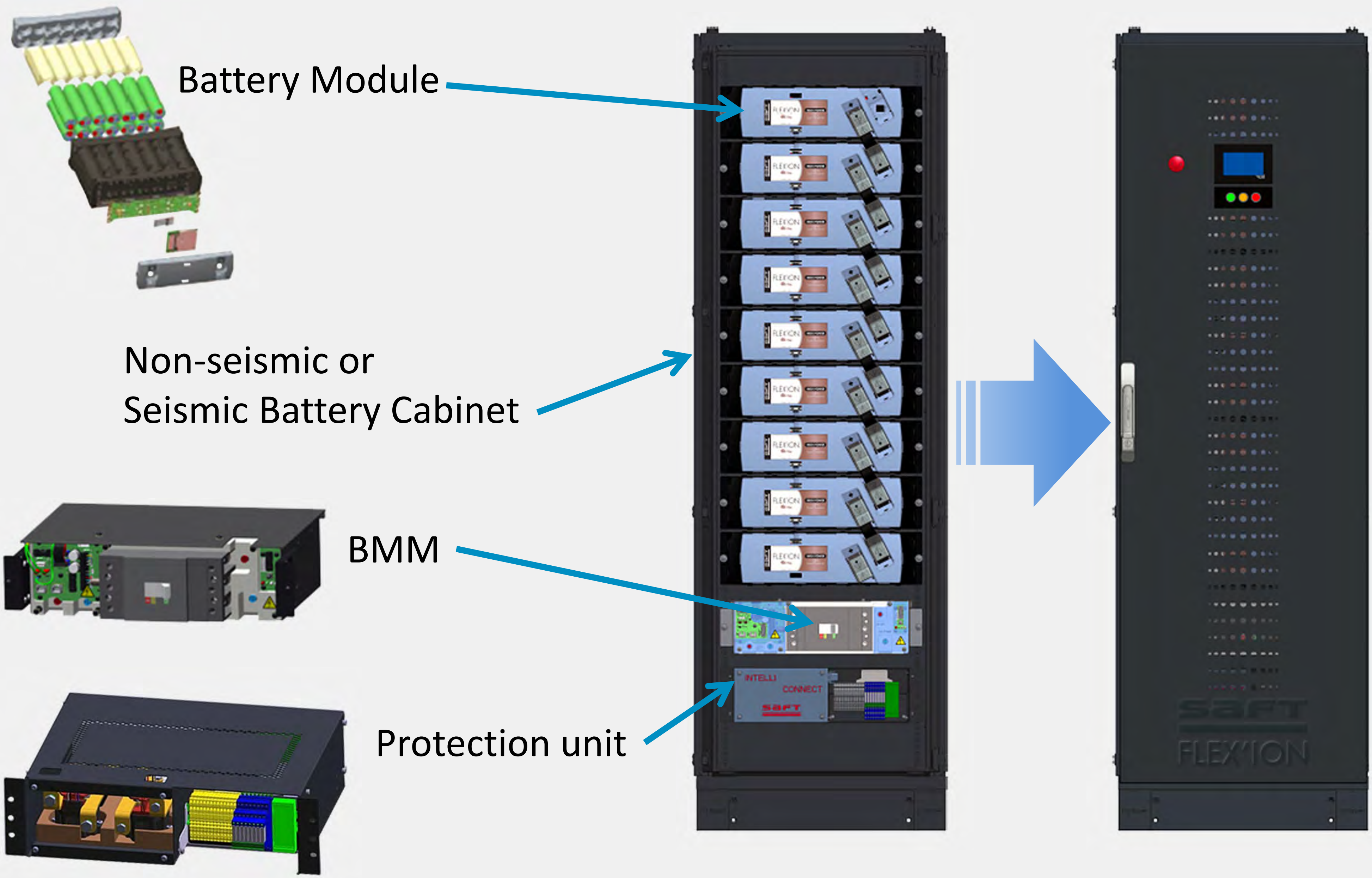
System Components



Battery Module – cutaway

Electronics Board

- Provides information to BMM
  - Voltage & temperature
  - Electrically balances cells

Lithium-ion Cylindrical Cells

Battery Module

- Power connections
- Signal / Communication connections
  - Communications protocols (CAN, Modbus, etc.)
  - SAFETY circuits

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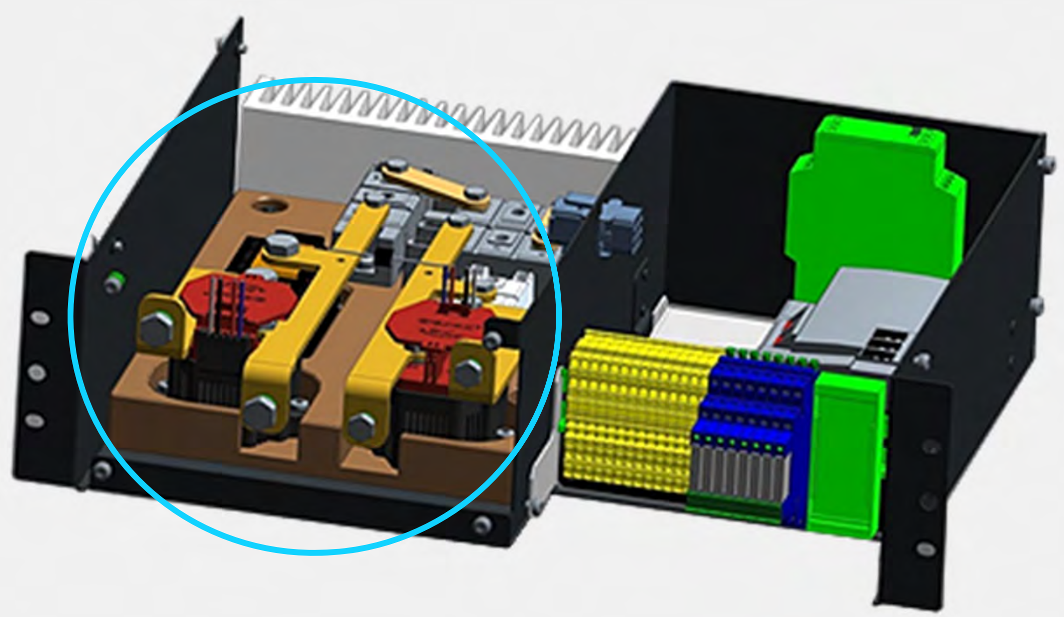
Battery Management Module (BMM)

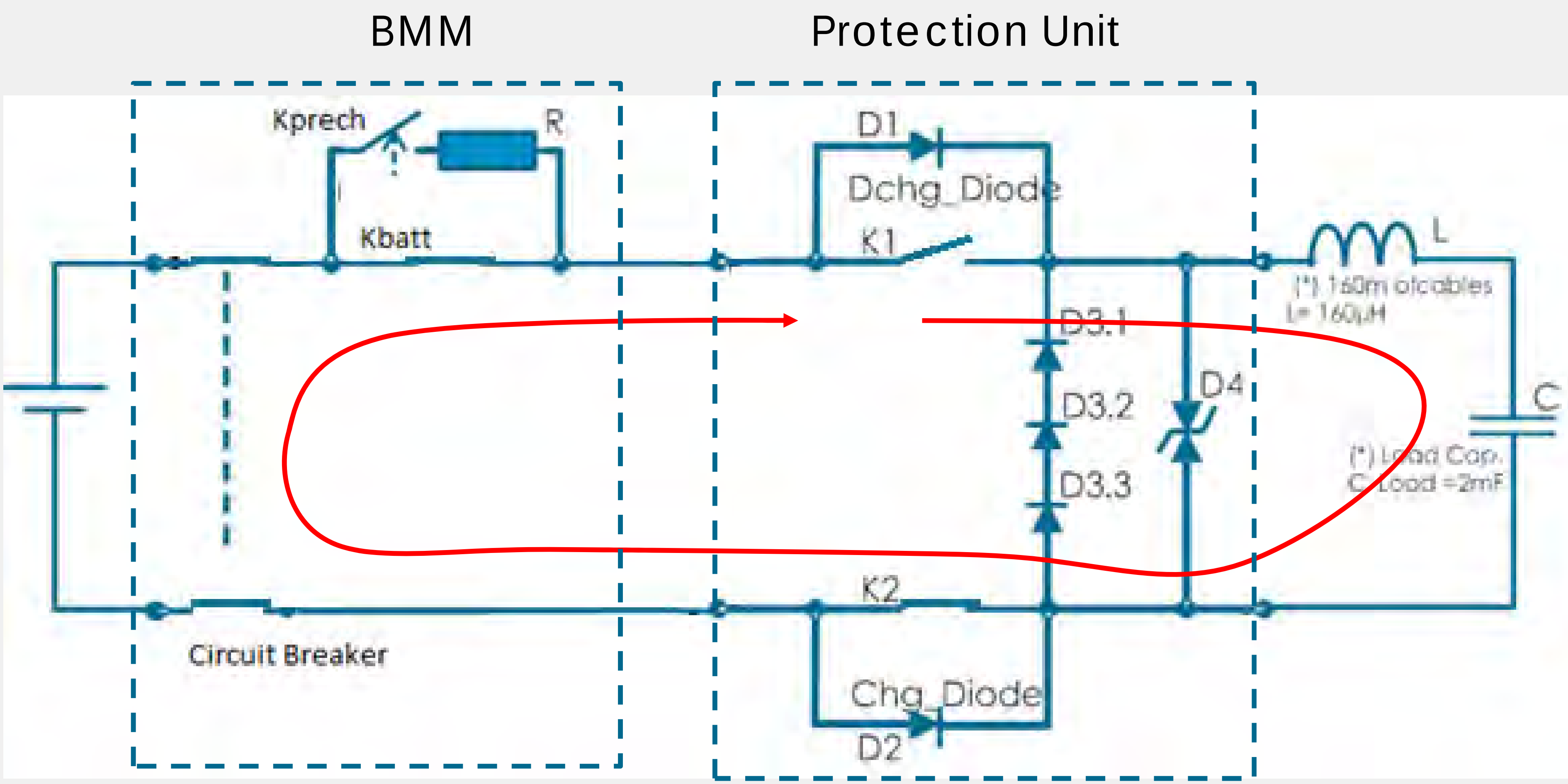
- **String Breaker**
- **Device includes**:
  - Control power supply, contactor & current measurement
- **Single electronics board**:
  - Battery management (system status, software functions, SOC/SOH/etc.,)
- **Communication**

Protection Module

– **Over Charge Protection**
  - Disconnects battery form charge circuit
  - Still allows discharge through a diode
– **Over Discharge Protection**
  - Disconnects battery from load when battery is empty.
  - Still allows charge through a diode

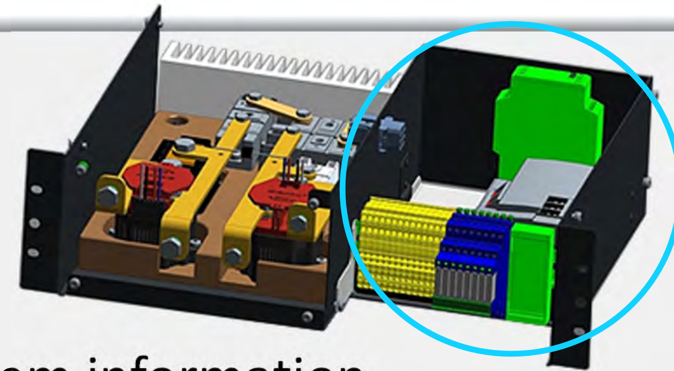


String Schematic



Discharge through diode with K1 open , but charge is stopped

Master Battery Monitoring Module (MBMM)



MBMM:

- **Master of communication**
  - Combines message from all strings for overall system information
  - Supports HMI
  - Internal Web page

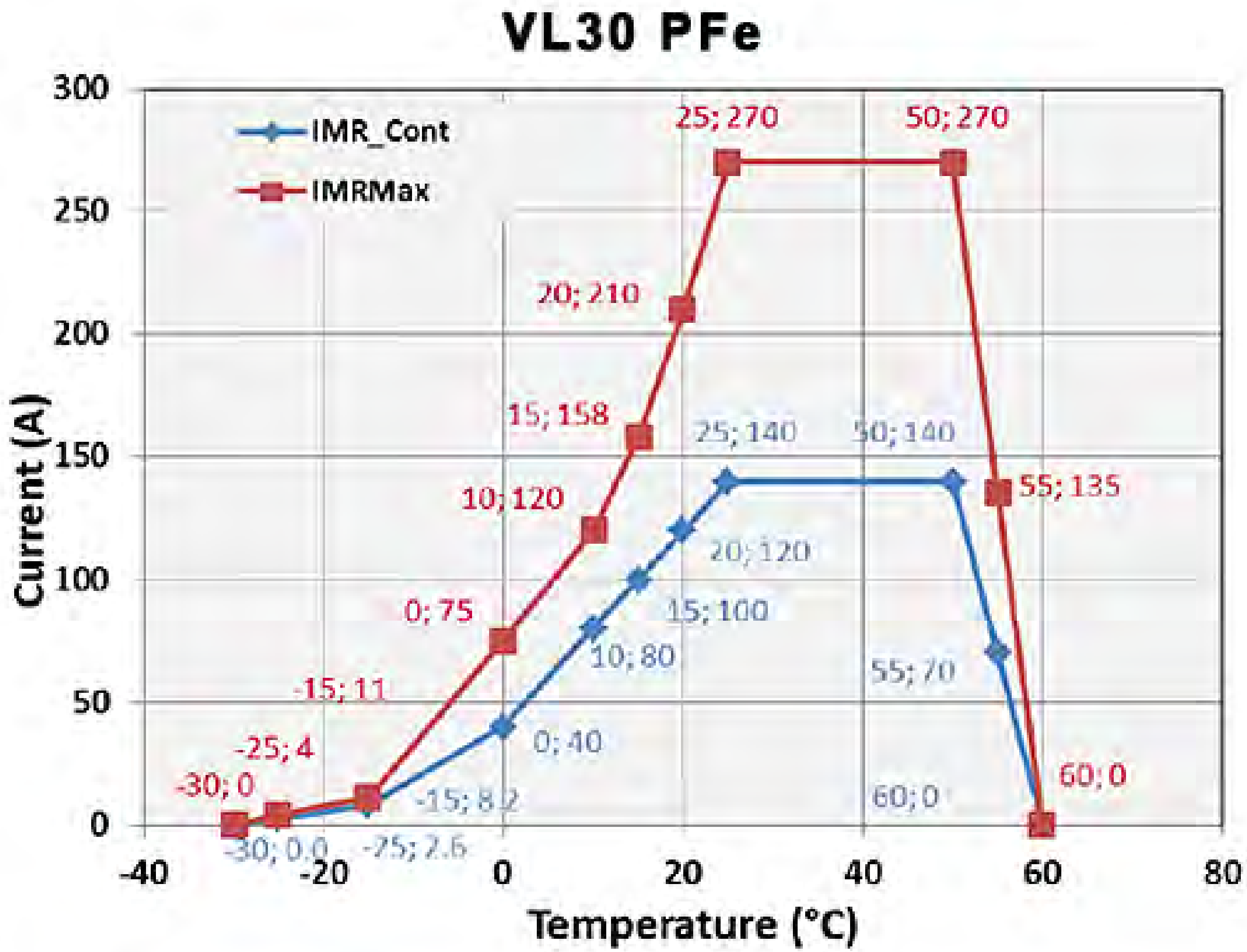
- **PLC based hardware**
  - Communication to customer supports:
    - CAN Open
    - Modbus (RS485 or TCP/IP)
    - Ethernet/IP
    - OPC

System Monitoring

Battery status information

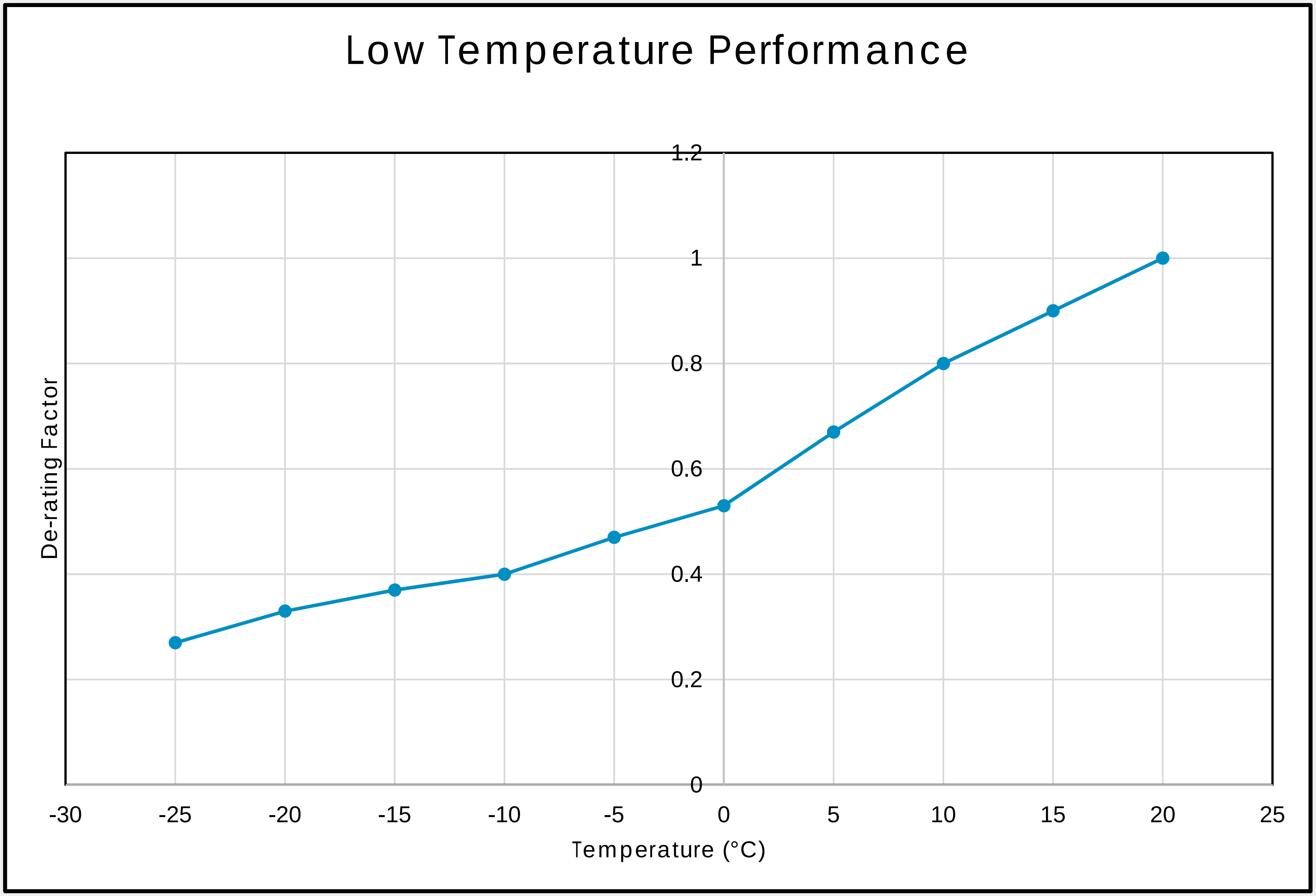
VCellMin	Fault
VCellMax	Battery mode
Tmax	MBMM watchdog
Tmin	# of BMM in parallel
IMD	# of BMM connected
IMR	# of BMM disconnected
SOH	Remaining capacity
SOC	Remaining energy
Ibat	To full charge energy
Vbat	VMD
Warning	VMR

Battery Charging vs Temperature



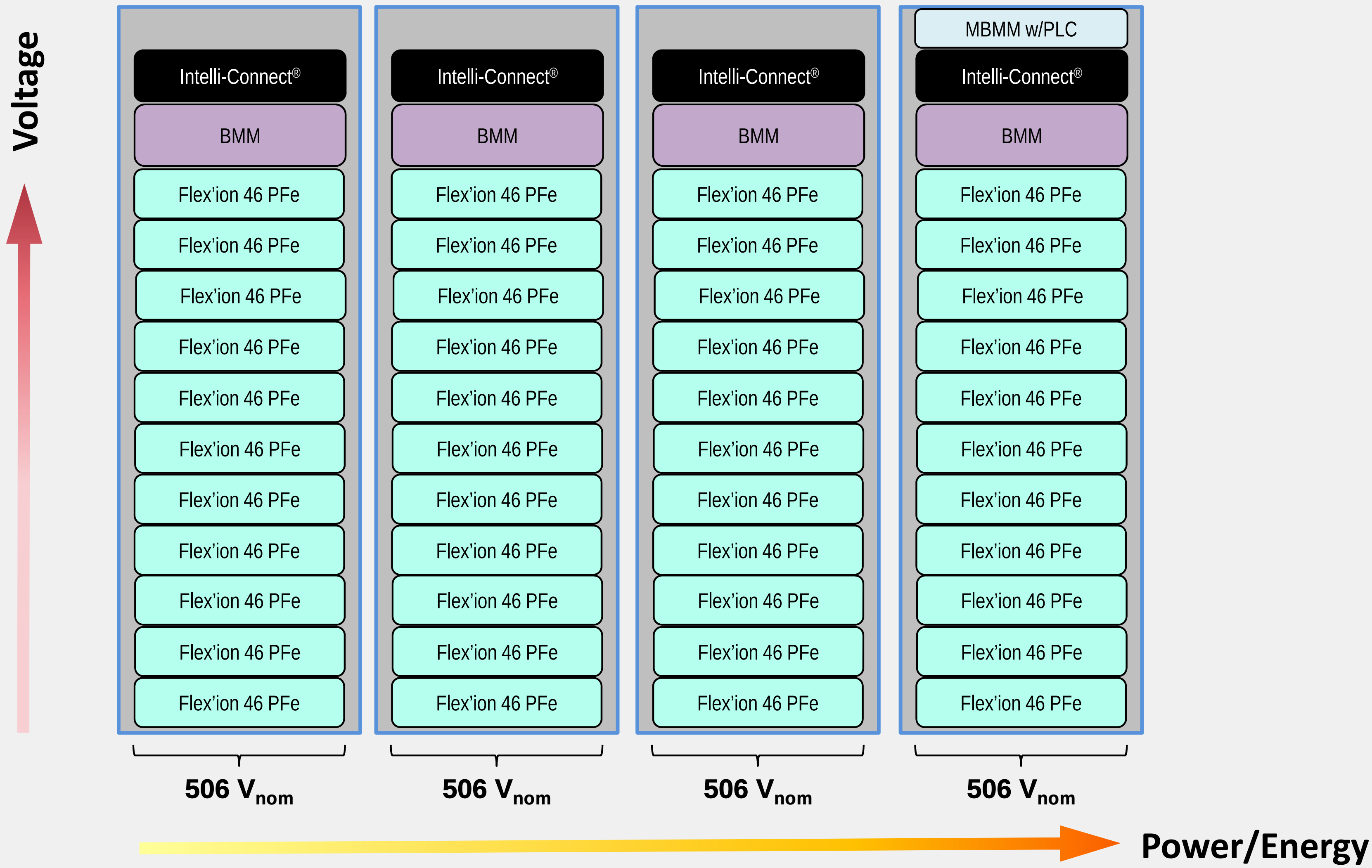
SOC [%]	0	67	85	90	100	102
IMR_cont	1	1	1	1	0.2	0.2
IMRMax	1	1	1	1	0.05	0

Capacity vs Temperature Lithium Ion



Modular System Example

Modular design allows flexibility



Applicable standards

Certification	Description
CE marking (incl. EN 50178 & IEC 60950)	Compliance
California Building Code 2013	Seismic Rating Requirements
International Building Code (UBC)	Seismic Rating Requirements
IEC 61587	Mechanical structures
IEC 61508	Functional Safety
IEC 62040-2	Safety for UPS
IEC 62477	Power Electronics Safety
IEC 62619	Li-ion Standard for Safety
IEEE 1679.1	Li-ion Evaluation
IEEE 693 2005	Seismic Rating Requirements
UL 94	Flammability of plastics
UL 1778	UPS Standard
UL 1973	ESS Stationary
UN 3480	Transport Class 9

BREAK?

4 BUILDING CODES

Building Codes are being developed for Lithium Ion

- New codes are adopted at different rates around the country
- Some areas lag 3-5 years behind new code release
- Other area move quickly to adopt new codes
- Check with your local AHJ for the location near you
- IFC and NFPA are beginning to converge on the same rules

Codes prior to 2018 (reference IFC)

TABLE 608.1
BATTERY REQUIREMENTS

REQUIREMENT	NONRECOMBINANT BATTERIES		RECOMBINANT BATTERIES		OTHER BATTERIES
	Vented (Flooded) Lead Acid Batteries	Vented (Flooded) Nickel-Cadmium (Ni-Cd) Batteries	Valve Regulated Lead-Acid (VRLA) Cells	Lithium-Ion Cells	Lithium Metal Cells
Safety caps	Venting caps (608.2.1)	Venting caps (608.2.1)	Self-resealing flame-arresting caps (608.2.2)	No caps	No caps
Thermal runaway management	Not required	Not required	Required (608.3)	Not required	Required (608.3)
Spill control	Required (608.5)	Required (608.5)	Not required	Not required	Not required
Neutralization	Required (608.5.1)	Required (608.5.1)	Required (608.5.2)	Not required	Not required
Ventilation	Required (608.6.1; 608.6.2)	Required (608.6.1; 608.6.2)	Required (608.6.1; 608.6.2)	Not required	Not required
Signage	Required (608.7)	Required (608.7)	Required (608.7)	Required (608.7)	Required (608.7)
Seismic protection	Required (608.8)	Required (608.8)	Required (608.8)	Required (608.8)	Required (608.8)
Smoke detection	Required (608.9)	Required (608.9)	Required (608.9)	Required (608.9)	Required (608.9)

2018 Codes and Standards

- NFPA 1, Chapter 52
- IFC 608
- 2018 editions

Source : Laurie Florence Battcon 2018 paper

Some Limitations imposed on Energy Storage Systems in the 2018 ICC IFC		
Parameter	Limitation Imposed	Exceptions
Threshold Quantities that must comply with IFC reqmts of Section 1206: • **lead acid or nickel** • **lithium, sodium and flow** • **other technologies**	 70 kWh 20 kWh 10 kWh	Hazard mitigation analysis per 1206.2.3
Size of Individual Array (BESS unit)	50 kWh	• Lead acid and nickel cadmium technologies, • 250 kWh for other technologies pre-engineered and pre-packaged if Listed • > 250 kWh for other technologies if Listed and if LSF testing &AHJ approval
Separation distances between BESS arrays or between arrays and structure	≥ 3 ft	• Lead acid and nickel cadmium technologies • Smaller separation distances for other technologies if Listed and if LSF testing & AHJ approval
Outdoor installation separation from exposures	≥ 5 ft	Smaller separation distances if LSF testing & AHJ approval
Maximum Allowable Quantities: • **lithium, flow or sodium** • **other**	 600 kWh 200 kWh	• Lead acid and nickel cadmium technologies • Group H-2 Occupancy • Hazard mitigation analysis is conducted, LSF testing & AHJ approval
Installation floor level limits: • **above lowest level of fire vehicle access** • **below lowest level of exit discharge**	 ≤ 75 ft ≥ 30 ft	• Lead acid and nickel cadmium technologies • > 75 ft above fire vehicle access if installed on noncombustible rooftop, does not restrict FF rooftop operations and if AHJ approval
AHJ – authority having jurisdiction **LSF – large scale fire testing, which can be addressed by the 9540A test method** **FF – fire fighter**		

Key Points for Lithium Ion

- Applies to systems over 20kWh
- Array size 50 kwh
- 3 feet spacing between arrays
- Maximum allowable quantity 600 kwh per fire area
- Limits on which floor of a build can have ESS
- AHJ may approve closer spacing with Large Scale Fire test report.

Codes and Standards

- Battery Management System (BMS)
  - Monitor and balance cell voltages, current and temperature
  - Must transmit alarms to an approved location

- Risk Mitigation and Failure mode analysis is required

Source : Randy Schubert Battcon 2018 paper

Codes and Standards

- Suppression:
  - 2015 editions did not explicitly required suppression
  - 2018 required for all battery spaced w/ exceptions for telecommunication installations
- Gas Detection
  - Alarming for 25% of the lower flammability level of gas as well as 50% of the IDLH (immediately dangerous to life or health) for toxic or highly toxic gases.
  - Must have visible and audible alarms in the battery room
  - Approved transmission to specific location
  - De-energizing of the battery rectified
  - Activation of the ventilation

What is LSF test?

– UL9540A – Large Scale Fire Testing
  - Evaluation of fire characteristics of a battery energy storage system that undergoes a thermal runaway event.
  - The data then serves to determine the required protection equipment for the installation.
    - Risk of Fire propagation (cell to cell, module or strings)
    - Amount of heat and gases generated
    - Fire service strategy and tactics
  - Outcome:
    - Separation requirements between arrays or strings and between walls
    - Ventilation require
    - Pre-planning for fire incidents

UL9540A Edition 4

- Cell level tests:
  - Determines thermal runaway conditions
    - Temperature at venting
    - Temperature at thermal runway initiation (ignition of electrolyte)
    - Cell vent gas generation composition
    - Lower Flammability Limit

- Module Test
  - Demonstration of the tendency for thermal runaway propagation within a module
    - Passing criteria is if cell to cell propagation doesn’t occur
    - No need to perform unit level testing

UL9540A Edition 4 (cont.)

- Unit level testing (string or cabinet level)
  - Document thermal runaway within a battery unit (cabinet or string)
  - Document flames outside the cabinet
  - Measurement of surface temperatures
  - Measurements of surround walls
  - Document any reignition that occurs

- Passing tests occur when:
  - No flames come outside cabinet
  - No explosion is observed
  - Max temperature does not exceed cell level temperature
  - Max surface wall temperature rise is less than 60C

- Installation level includes sprinklers or other suppression and containment methods
  - Only required when needed.

Applicable Building Codes / Standards

Building Codes

- NFPA-1 Fire Code, 2015
- NFPA-1 Fire Code, 2018
- IFC International Fire Code, 2015
- IFC International Fire Code, 2018
- NFPA-855, 2019
- NFPA-111, 2014
- NFPA-111, 2017 First Draft
- NEC-70 National Electric Code, 2017
- International Building Code, 2015
- International Mechanical Code, 2015
- NFPA-76, Standard for the Fire Protection of Telecommunications Facilities, 2015

Material Standards

- UL1973
- UL9540
- UL9540(A)
- UL94

THANK YOU